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 * Wind Shear Predictive Detector Technology Study Status *
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. Presentation of French Civil Aviation Technical Service
(C.GANDOLFI from DGAC/STNA/3E).

at

Second Combined Manufacturers' and Technology Airborne
Wind Shear Review Meeting, Williamsburg October 18-20, 1988

I) Introduction :

Among the different elements to be investigated when considering the Wind Shear hazard, STNA/3E [1], whose task is to participate in the development of new technologies and equipments, focused its effort on airborne and ground sensors for the detection of low-level wind shear.

The first task, initiated in 1986, consists in the evaluation of three candidate technics for forward-looking sensors : LIDAR (Light Detection And Ranging), SODAR (Sound Wave Detection And Ranging) and RADAR.

No development is presently foreseen for an infrared based air turbulence advance warning system although some flight experiments took place in the 70's. A Thomson-CSF infrared radiometer was then installed on an Air France Boeing 707 to evaluate its capability of detecting clear air turbulence. The conclusion showed that this technic was apparently able to detect clouds layers but that additional experiments were needed; on the other hand, the rarity of the phenomenon and the difficulty to operate on a commercial aircraft were also mentionned.

II) LIDAR program :

Laser technology is the only one that is presently studied for an airborne forward-looking sensor.

1) The first step of the LIDAR program consisted in a preliminary contract with the CROUZET company. This task initiated in may 1987 was completed by february 1988.

It consisted in the following elements :

- *investigation of operational objectives in terms of functional specifications and system design requirements : altitude and range of measurement, speed range, environmental constraints (weather, installation, ...), ...

*ground experiments with an existing mock-up sponsored by military contracts for anemometry purposes. This equipment is based on a continuous laser beam (10,6 μm), with a 75 mm telescope focusing between 10 and 100 m; the speed sign can be detected and measures around zero ($\pm 0,25$ m/s) are possible.

*evaluation for both adaptations : ground and onboard detector.

1.1 : Airborne wind shear detection :

General requirements :

The warning criteria recommended by the CROUZET company proceeds in two steps :

*a pre-alarm advisory for an increasing headwind of 40 ft/s combined with an upward vertical component;

*an alarm announce for a tailwind of 40 ft/s associated with a vertical downdraft.

The proposed technical requirements are the following ones :

*Radial speeds range from 60 to 240 knots (assuming aircraft speed between 120 and 130 knots and a wind variation of ± 60 knots);

*Velocity resolution : ± 3 knots;

*Look-ahead range of 700 m (10 s warning time) with a range resolution ≤ 300 m;

*Estimation of the vertical wind inferred from radial speed measurements in two spatially shifted locations;

*Lateral exploration by a conical scanning steered at 10° from flight path. "Left lateral", "right lateral", "up", "down" components would be delivered with an update rate of approximately 1 s;

*Environmental constraints as defined in RTCA-DO160-B.

The resulting information presented to the pilot would be the radial velocity (V_x), an estimation of the vertical component (V_z) and the lateral shifting of the perturbation (V_x right and V_x left).

Two technologies are proposed by the CROUZET company :

*at first, a mock-up based on a continuous CO_2 laser source (10,6 μm) with a MTBF (Mean Time Between Failure) of 1000 hours;

*in the future, for operational systems, a solid-state laser (2,1 μm) with a MTBF of 5000 hours, an half size optical diameter, a classical thermal regulation.

Future studies proposals :

*The first idea was to proceed with flight experiments of the existing mock-up where a 200 mm telescope would have been adapted in order to focus at 570 m (measurement volume between 420 m and 720 m) using conical scanning of 1 s and beam steering of 10°. The aim was to collect data on V_x laser, V_z laser, the difference between laser speed and aircraft speed, and spectra. This program didn't appear efficient enough since the technological options were not clearly defined at this stage. It seemed necessary to precisely identify the theoretical environment before carrying out expensive flight tests.

*Consequently, a second program plan was considered on the basis of flight tests supported by theoretical tasks and simulations. However, since the main technological choices (type of laser, optical diameter, ...) had to be fixed through simulation investigations, it was decided to delay the experimental phase.

The preliminary theoretical part was delegated to the ONERA research laboratory [2] because of its experience in detectors, aircraft simulators, aerodynamics, and its relationships with meteorologists as well as with people from the National Flight Test Center "CEV" [3]. Another point is that an equivalent method combining a theoretical part carried out by a research center and a realization through a mock-up designed by a manufacturer proved successful for the anemometry prototype (cooperation ONERA/CROUZET).

ONERA program plan :

The contract concerning the ONERA participation is presently to be debated but preliminary guidelines have been identified in terms of an initial study to start with. It concerns :

- *the windshear models :

- implementation of the existing FAA models
- adaptation of new parameters specific to laser detection such as variations of the backscattered signal, absorption, rain and fog attenuation, ...

- *simulations with different types of laser sensors : continuous CO_2 source with or without modulation, pulsed laser, optical diameter, ...

1.2 : Ground-based wind shear detection :

General requirements :

The operational requirements as defined by CROUZET assume a coverage until 1000 ft that is considered to be the minimum safe altitude to monitor take-off (6°) and landing (3°) flight paths.

From the various constraints (length and width of runway, lateral shifting of microburst, warning time of 10 s), a minimum range of 7,5 Km is required for a ground sensor located at the center of the runway and alternatively

scanning departure and arrival flight paths. According to the cost and availability of technology, an alternate solution can consist of two systems focusing at 2400 m (measurement volume between 40 m and 3400 m). The spatial resolution must be better than 300 m for a range of speed of ± 60 knots with a speed resolution of ± 3 knots.

Among the constraints, the environmental severity factor must be taken into account : electrical protection, temperature ($-30^{\circ}\text{C}/60^{\circ}\text{C}$), humidity, sand and dust, salt spray, ... The foreseen MTBF is 5000 hours.

Another essential aspect is that in order to be efficient, a ground-based equipment needs an automatic alert transmission.

Ground-based experiments :

The equipment is based on a continuous laser source ($10,6\ \mu\text{m}$), with a 75 mm telescope focusing between 10 and 100 m. However, in order to increase the range, some measurements were done at 200 m ([50m, 350m]).

Preliminary tests were settled in CROUZET facilities in order to observe building-induced turbulence. Despite CROUZET conclusions, this experiment didn't prove demonstrative since the collected values didn't show a sufficient amplitude dynamic (0 to 4 m/s).

The first set of tests consisted of :

- preliminary measurements with a fixed mirror and focusing distance of 35 m;

- conical scanning : beam steering at 15° orientation and 40 rounds per minute for a focusing distance of 200 m. The theoretical graph is a sinusoid whose mean value depends on the wind component along line of sight. The amplitude is a function of the perpendicular component module; the phase is related to its orientation. Wind field dispersion distorts the ideal curve.

Several rotation speeds were experimented. Since the angular shifting of line of sight cannot be omitted any longer during the acquisition of instantaneous spectra for one measurement, the spectrum width increases with the rotation speed.

- measurements in rain conditions : the spectrum enlarges because of rapidly changing speeds of turbulence and rain. In some experiments, rain drops speed signal was more powerful than wind speed itself.

The system was then installed on the military base of Valence. The frequent proximity of helicopters at low altitude gave the opportunity to collect data on turbulence engendered by their rotor blades.

- variation of the focusing distance from 30 m to 200 m showing the spectrum spreading at "long distance".

-measurement volume splitting by putting a mirror on the line of sight in order to demonstrate the capability of indicating the change of sign in velocity.

Future studies proposals :

The pulsed technique is the only valid candidate for the 7,5 Km range criteria. Furthermore, it guarantees a spatial resolution proportional to the pulse length and light celerity. Since ground clutter isn't a sensitive point, a slight deviation of laser beam (2° tilt) could be used to evaluate phenomenon shifting.

An alternate solution, proposed by CROUZET, is to use two equipments located at 2400 m from each runway extremity and monitoring a smaller zone : 40 m to 3400 m. This system would be based on a continuous laser with adaptative focusing distance. A 30 cm telescope would be used in order to conciliate cost constraints and atmospheric turbulence effects. The spatial resolution rapidly deteriorates with distance. According to CROUZET, a measurement could be correctly located for distances up to 1 Km and beyond detection would still be possible for spread and quite homogeneous phenomena. The idea consists in frequency coding of emission. This method was tested and validated for distances lower than 1 Km but it must be experimented for greater range since it seriously decreases the signal to noise ratio. It could also be a mean of getting rid of undesired targets (insects, birds, ...).

1.3 : Conclusion :

The efficiency of the LIDAR technic is obviously mostly limited by attenuation due to rain, fog and by perturbations engendered by moving point clutter (birds, insects, ...).

Concerning the laser source itself, the continuous CO₂ technology is available but pulsed and solid-state lasers need further development.

In France, airborne LIDAR is also experimented for vertical wind profiles by the Dynamic Meteorology Laboratory.

Although CROUZET existing laser anemometry prototype is well adapted for anemometry purposes, it didn't appear well suited for a transformation into a wind shear detector. Furthermore, from preliminary studies, it seems more efficient to study the option of an airborne LIDAR rather than a ground-based equipment. That's why, further research work will be done by the ONERA laboratory before proceeding to the design, integration and validation of an airborne LIDAR in a flight demonstration program.

2) The second step of the LIDAR program is not yet defined but a preliminary study is to be started with ONERA laboratory (cf 1.1).

III) SODAR program :

1) Program objectives and methodology :

The SODAR system (developped by the REMTECH company) analyses the backscattered wave resulting from emission of sound pulses. The returned signal will be Doppler shifted in frequency by an amount proportional to the backscattering cells representative of wind velocity.

The first generation of SODARs included three horn fed dishes with one vertical antenna and the two other ones slightly vertically tilted. The whole thing was enclosed in an absorbant protecting material. This equipment had been designed to collect wind field direction and intensity in the low altitude atmosphere layers for pollution detection purposes mostly.

The aim of the contract between French Civil Aviation and Remtech Co. was to examine whether it was feasible to adapt this type of equipment for ground-based wind shear detection along take-off and landing flight paths.

The evaluation guidelines concerned :

- *environmental problems : surrounding noise, influence of aircraft noise, ...;
- *sound pollution generated by the equipment;
- *influence of ground proximity at low tilt : noise, acoustic rays curvature, ground clutter;
- *feasability of a "megasodar" supposed to reach 6 Kms by using a multicellular antenna.

The conclusion of this contract notified in may 1987 was supposed to make a comparison between directivity patterns calculated in simulations and experimental results in order to check whether it's valid to extrapolate for a multicellular antenna.

2) Program evolution :

The feeble performances of the horn fed dish antenna made it impossible to carry out all the necessary measurements. Consequently, the realization of a multicellular antenna mock-up became absolutely necessary. That's why, the priorities previously defined had to be changed. Furthermore, the bad wheather conditions of spring 1987 in Paris during the installation on Roissy airport delayed the experimental phase that is still going on.

The theoretical part consisted in test antenna optimization (2,4 m diameter horn fed dish antenna). At a given frequency, the only parameter that can be modified is the illumination function. In order to evaluate the characteristics in the far-field, directivity calculations were done by simulations for various amplitude distributions with phase locked. Obstacle effects were simulated by approximated calulations.

3) Experimental phase :

It was organized in three parts :

- *measurement of the antenna characteristics;
- *quantification of physical influences;
- *wind measurements.

Directivity measurements showed good agreement between theoretical and effective patterns for angles lower than 4° and an important discrepancy beyond, resulting in high sensitivity to ground clutter. It was assumed (and experimentally confirmed afterwards) that this difference was caused by the obstacle effect generated by the antenna feed (horn of 25 cm). Directivity measurements using a piezo-electric tweeter of 8 cm resulted in good agreement with theory but the improvement for ground clutter is of only 6 dB.

Despite the poor performances of the first antenna configuration (JBL antenna feed of 25 cm), some measurements series were recorded with an emission at 4000 Hz and several tilts were analyzed. It showed the important influence of temperature and humidity on atmospheric absorption. These reflectivity fluctuations induce variations of range from 290 m to 180 m.

Another testing bench with the second antenna configuration (tweeter + dish antenna) showed that, despite the ground clutter elimination algorithm, in some cases, wind measurements were irrelevant. The data processing needed a manual analysis in order to guarantee good agreement with wind speeds recorded from an anemometer (from National Meteorology) located on the airport.

In order to prove "megasonar" feasibility, the REMTECH company decided to build a small-scale multicellular antenna mock-up using a rectangular array of tweeters.

The main anticipated advantages are :

- *elimination of obstacle effects;
- *independant amplitude tuning;
- *beam steering by phase shifting among the different elements;
- *increase of power (number of elements).

However, the interaction between elements hasn't been taken into account and this assumption must be checked by further experiments.

4) Conclusion :

The small-scale multicellular mock-up was designed to reduce complexity by minimizing the quantity of independant elements. Since the major problem concerned the vertical plane, the amplitude tuning will only be applied to the vertical section and there will be less antenna feeds on the lines than on the columns. Because of their great dispersion, the tweeters were previously tested and selected. This array is made of 392 elements with a spacing of 8.85 cm and distributed into 23 lines and 14 columns for a surface of 2.5 m x 1.25 m.

Theoretical calculations of the estimated range were done. The multicellular mock-up will be taken up soon in order to be experimented. The success of this stage is crucial since the lack of performance of previous antenna configurations made it impossible to demonstrate the ability of this technic to detect wind shear.

IV) Ground-based RADAR program :

1) Introduction :

Wave-length is a crucial parameter for radar detection. With wave-lengths ≤ 5 cm, it's possible to design small antennas with high angular resolution ($\ll 3^\circ$), resulting in good vertical resolution for wind profiles and a good protection against ground clutter. However, an experimental program carried out by the CRPE [4] in 1985 showed that this type of radar couldn't correctly measure in clear air condition. It was theoretically concluded that, in order to operate in clear air as well as in rain conditions, for a radar of 4.5 Kw peak power equipped with a 5 m antenna, the optimal bandwidth ranged from 20 to 35 cm.

The laboratory designed a 30 cm radar (4.5 Kw peak power) for atmospheric research purposes (PROUST system). With a 11 m antenna, this equipment proved able to vertically observe the troposphere up to 10 Kms. Of course, the use of a 5 m antenna will decrease the clear air detection level of 7 dB but a compensation from the turbulent energy gain is anticipated.

Consequently, the UHF radar hold the attention as a feasible candidate in ground wind shear detection.

2) Program objectives :

An agreement was signed with CNET/CRPE [4] in order to study the feasibility of wind shear detection both in clear air and rain conditions using a ground-based radar.

The aim is to perfect design criteria for a specialized radar by theoretical and experimental studies with the following operational constraints :

- *radial measurement of windshear along departure and arrival flight paths;
- *detection in both clear air and rain conditions;
- *range : 600 m to 10 Kms;
- *range resolution : ≤ 600 m;
- *angular resolution : $\leq 3^\circ$;
- *speed resolution : $5 \cdot 10^{-2} \text{ s}^{-1}$;
- *false alarm rate : $< 10\%$;
- *moderate cost : $\leq 3 \text{ MF}$ ($\leq 600,000$ \$);
- *peak transmission power : $\leq 5 \text{ Kw}$;
- *antenna diameter : $\leq 5 \text{ m}$.

3) Program planning:

3.1 *Evaluation of 30 cm radars performances at low horizontal tilt in wind shear conditions :*

- *Ground clutter calculations,
(July 1988);
- *Wind shear models implementation on simulator,
Radar characteristics optimization,
(September 1988);
- *Shadow effect generated by aircraft,
Simulation of radar spectra with ground
clutter,
Wind profiles extraction,
(May 1988);
- *Experimental evaluation with PROUST radar and
ground clutter and aircraft signatures,
(May 1988);

3.2 *Evaluation of feasibility on airport :*

- *Synthesis of previous tasks,
(November 1988);
- *Additional theoretical studies and definition
of an adapted antenna,
(May 1989);
- *Measurements of wind shears and/or turbulence
on airport,
(date not fixed);

3.3 *Conclusion :*

(November 1990);

4) Program evolution :

* Wind shear models (historical, AC120_41, JAWS models) were implemented and tested on CNET computer facilities for simulation. From the discontinuous distribution of wind speeds, a continuous wind field was produced by using the techniques described in the JAWS program. Radar spectrum response within a wind shear field can then be anticipated gate by gate.

* Ground clutter modelling is based on gate/ground contact surface and random distribution law of the obstacles (a hundred obstacles of 10^4 m² each for all the gates).

* Aircraft clutter elimination is the next point to be studied. Research work concerns :

- antenna optimization (to be studied in 2.2 phase);
- radar processing :
 - case of aircraft on main lobe : saturation, signal attenuation before reception, elimination algorithm;
 - case of aircraft on sidelobe : elimination algorithm with spectral signature of aircraft.

5) Program continuation :

5.1 Aircraft clutter elimination : (June 1989)

- *New algorithms for elimination;
- *Simulation and test of previous methods of elimination;
- *Statistic study of aircraft clutter;

5.2 Ploemeur Bodou experimentation : (June 1989)

- *Definition of experiments and schedule;
- *Experiments with antenna tilted at 45°;
- *Measurements analysis : experimental results of clutter elimination methods performances.

5.3 Installation on airport : (September 1989)

- *Definition of optimal antenna : sidelobes attenuation (absorbant material, lattice-work, trench), antenna feed, radiated pattern;
- *Definition of the optimal location for installation : ground clutter minimization for main lobe and first sidelobes, ground clutter map, possibility of making a trench, aircraft return reduction by carefully positionning antenna lobes in relation to taxiways, departure and arrival flight paths.

6) Preliminary theoretical results :

6.1 Spectral width :

Among the main causes of increase of spectrum width such as distribution of scattering cells speeds, turbulent field mean quadratic speed, limited width of beam, sampling rate, non ambiguous distance, wind shear is the most contributing one, resulting in radar capability in providing relevant measurements.

6.2 Measurement Accuracy :

Assumption : in the elementary volume chosen for simulations (30mx30mx30m), the radial speed is supposed to be constant.

Simulation showed that for low-altitude horizontal wind shear structures (inversion layer, thermic wind) localization can be impossible for several gates. For vertical wind field distributions, the radar delivers a precise localization of the phenomenon.

Minimum reflectivity factor (C_n^2) required to guarantee a good detectability at 10 Kms was evaluated as a function of wind shear intensity per gate. Wind shear detection at 10 Kms requires an equivalent reflectivity factor Z_e of - 10 dBz for a wind difference (in a gate of 600 m) of 8 m/s (\approx 16 knots) and of - 2 dBz for 30 m/s (\approx 60 knots). These results do not depend on antenna aperture that can eventually modify extreme wind speed measured because of the variation of the volume observed.

6.3 Safety requirements :

For the pilot :

- *Detect wind shear,
- *Identify its type,
- *Quantify its intensity,
- *Localize it,
- *Anticipate its evolution;

For the tower officer :

- *Wind speed and direction,
 - *Anticipation on phenomenon duration,
 - *15 mn prevision of possible occurrence.
- (as defined by the CLAWS program).

An alert system combining radar detection and meteorology analysis is presently foreseen in order to decrease false alarm rate. At the beginning, human intervention will be necessary but automatization of the whole process needs to be developped in a further stage. High collaboration between radar operators and meteorologists is necessary to develop and fix a performant wind shear alert algorithm but meteorological research hasn't begun yet.

6.4 Non atmospheric returns :

High power targets may be all the more detected by the radar as the horizontal tilt of the antenna is low. These spurious echoes are a serious danger for wind shear detection since the wind tracers have got a smaller cross section. This results in two consequences :

- *saturation of radar input level,
- *superposition of two signatures of highly different power.

Main bibliographical results on efficient section influence were summarized. Spectral width increase due to ground clutter was experimentally evaluated with PROUST radar (30 cm). The main results are the following ones :

*phase stability at short term is crucial; it should be better than 10^{-2} Hz ($2 \cdot 10^{-3}$ m/s);

*Doppler jitter highly varies with season (winter/summer), humidity and wind ground;

*In order to quantify spectral increase due to ground clutter, the increase must be defined from the amplitude corresponding to the noise, that is the width for a signal to noise ratio taking into account the return statistical dispersion;

*The absolute limits variations due to multipaths, Fourier transform of a temporal limited function, echo structure jitter range from $DV = 1$ m/s to 2 m/s.

Estimations of signal to clutter ratio show that it is necessary to decrease ground clutter level of 60 dB in order to guarantee atmospheric detection for the first gates. Another point is that these echoes create a Doppler zone of ± 1 m/s where wind shear detection may be difficult. A method was developped in order to detect atmospheric echoes with amplitudes and Doppler shifts lower than those typical of fixed echoes. This method makes it possible to detect atmospheric echoes with ground clutter for a signal to noise

ratio of - 30 dB and Doppler shifts of 0.25 m/s. As long as the analogic signal doesn't saturate amplification and exceed analogic/numeric converter capability, wind shear detection should be provided.

6.5 Fixed echoes elimination :

Angular and temporal filtering methods of analogic signal were investigated. The methods that are presently foreseen for the PROUST radar are :

*"distance gate MTI" (Skolnik,1981) : selection of the main spectrum line and rejection of the central zone "polluted" by fixed echoes; this technic needs phase stability to be efficient;

*adjustement of the ground model to the spectrum; this method is presently tested on the PROUST radar and makes it possible to discriminate useful and undesired echoes.

6.6 Preliminary conclusions :

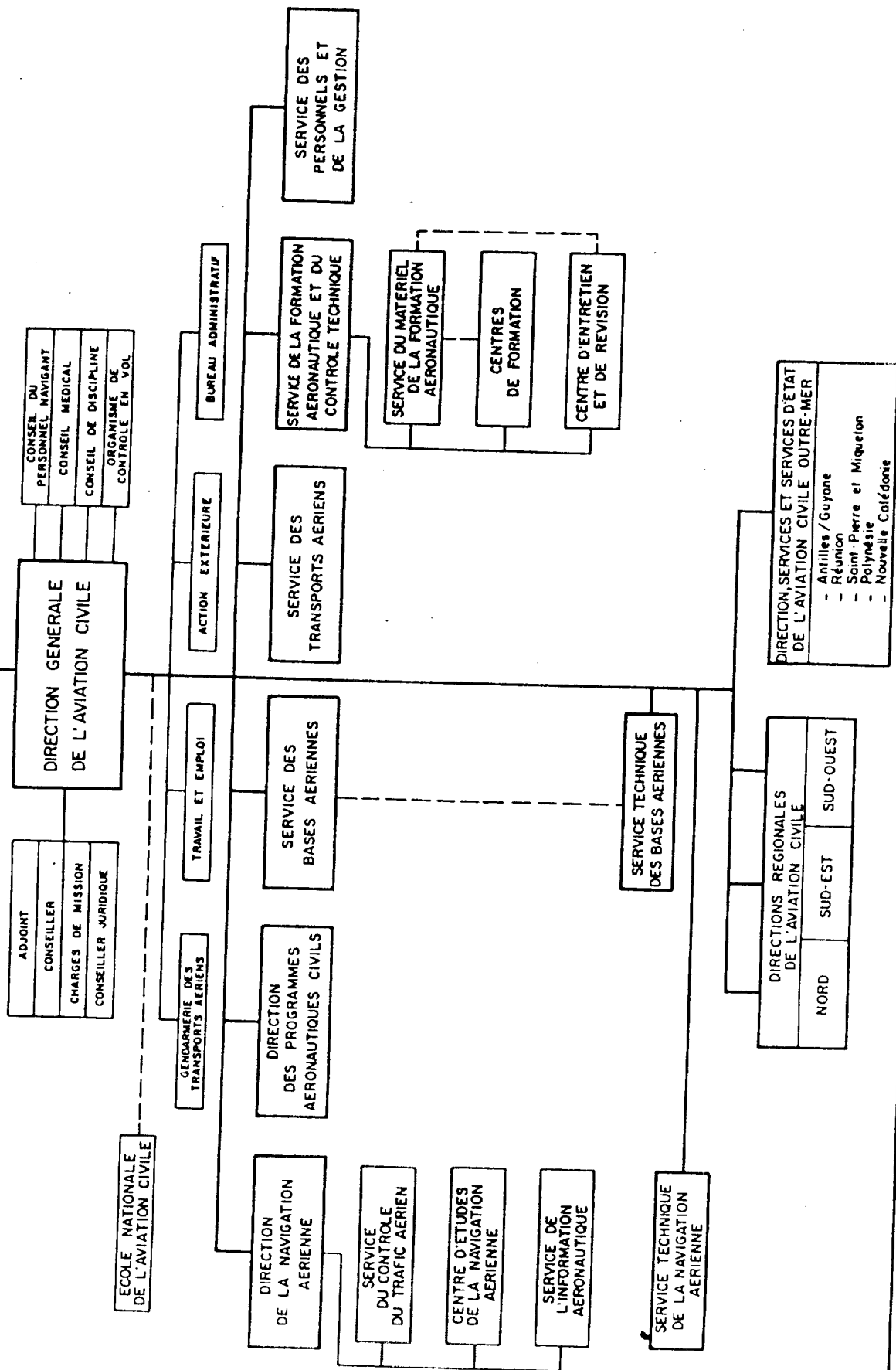
*ground clutter dynamic : it should be suppressed by improving antenna efficiency and using numerical filtering methods.

*very low altitudes detection ($\ll 100$ m) at short distance from GPIIP : a technic consisting of gates of variable length will soon be simulated for evaluation.

IV) Abbreviations :

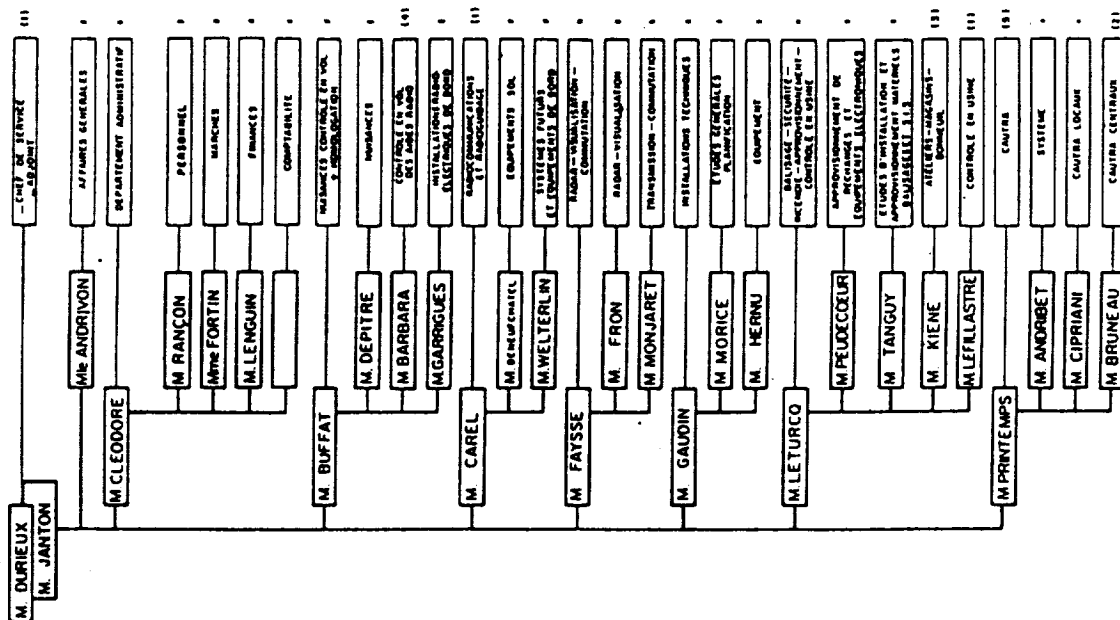
- [1] Aeronautical Navigation Technical Service (cf Annex 1)
Service Technique de la Navigation Aérienne
- [2] Aérospatial Studies and Research National Office
Office National d'Etudes et de Recherches Aérospatiales
- [3] National Flight Test Center
Centre d'Essais en vol (CEV)
- [4] CNET : Telecommunication Research National Center
Centre National d'Etudes des Télécommunications
CNRS : Scientific Research National Center
Centre National de Recherche Scientifique
CRPE : Environmental Physics Research Center, laboratory jointly sponsored by CNET and CNRS.
Centre de Recherche en Physique de l'Environnement

Ministère de l'équipement, du logement, de l'aménagement du territoire et des transports
Ministre délégué chargé des transports



II

SERVICE TECHNIQUE DE LA NAVIGATION AERIEENNE



(1) - 246, Rue Lecourbe
75732 PARIS CEDEX 15

TELEX
TELECOPIE

(2) - 91205 ATHIS MONS CEDEX

TELECOPIE

(3) - 31, Avenue du Maréchal Leclerc
Boite Postale 5
94360 BONNEUIL SUR MARNE

TELEX
TELECOPIE

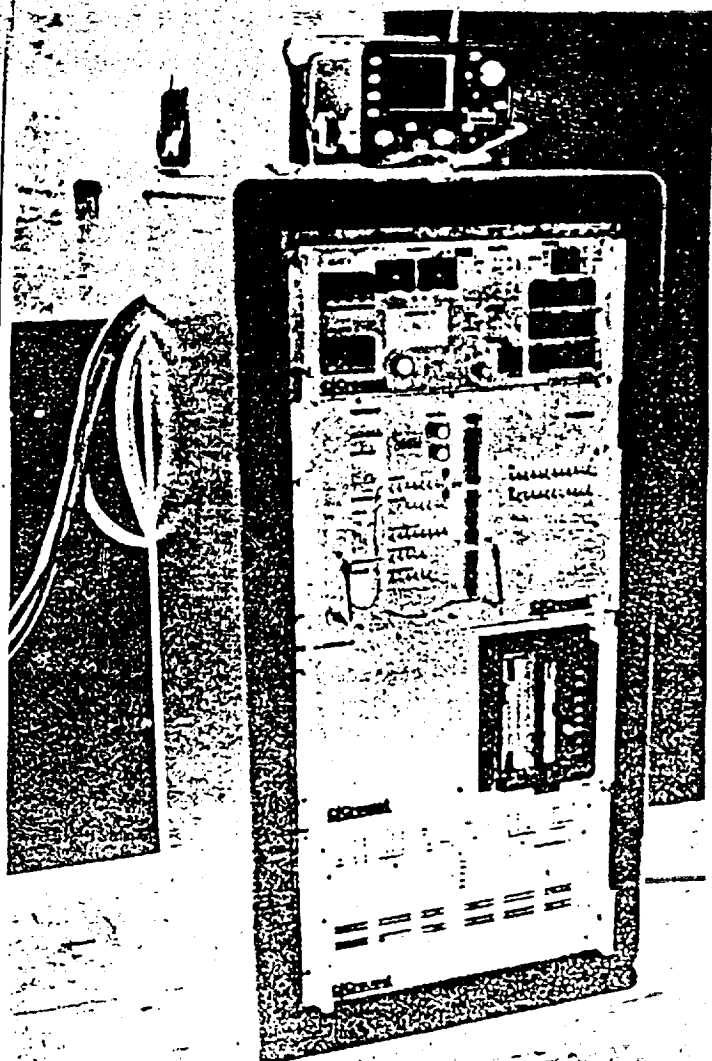
(4) - Aérodrome de Melun-Villaroche
77550 MOISSY CHAMAYEL

TELEX
TELECOPIE

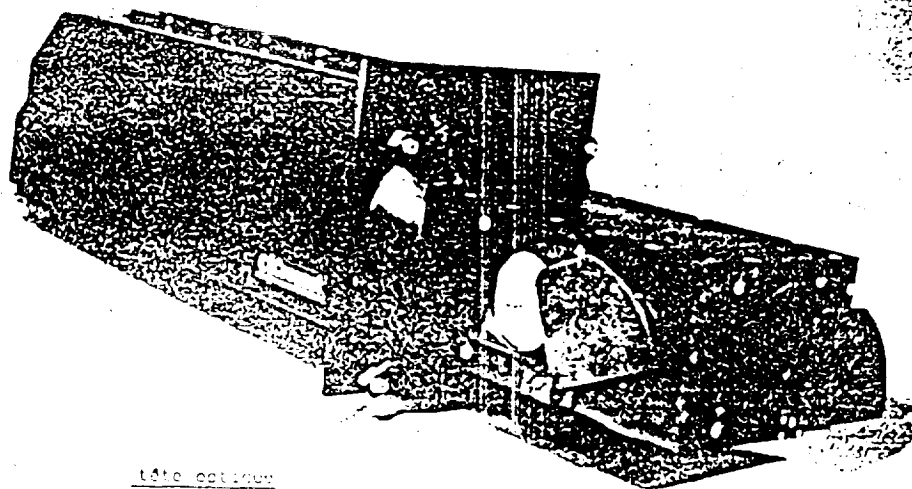
(5) - 95, Rue Henri Rochefort
91000 EVRY

NOTA : le "Cautra Centraux", actuellement à ATHIS-MONS (2), sera regroupé à EVRY (5), département Cautra, en juin 1988.

PLANCHE 1

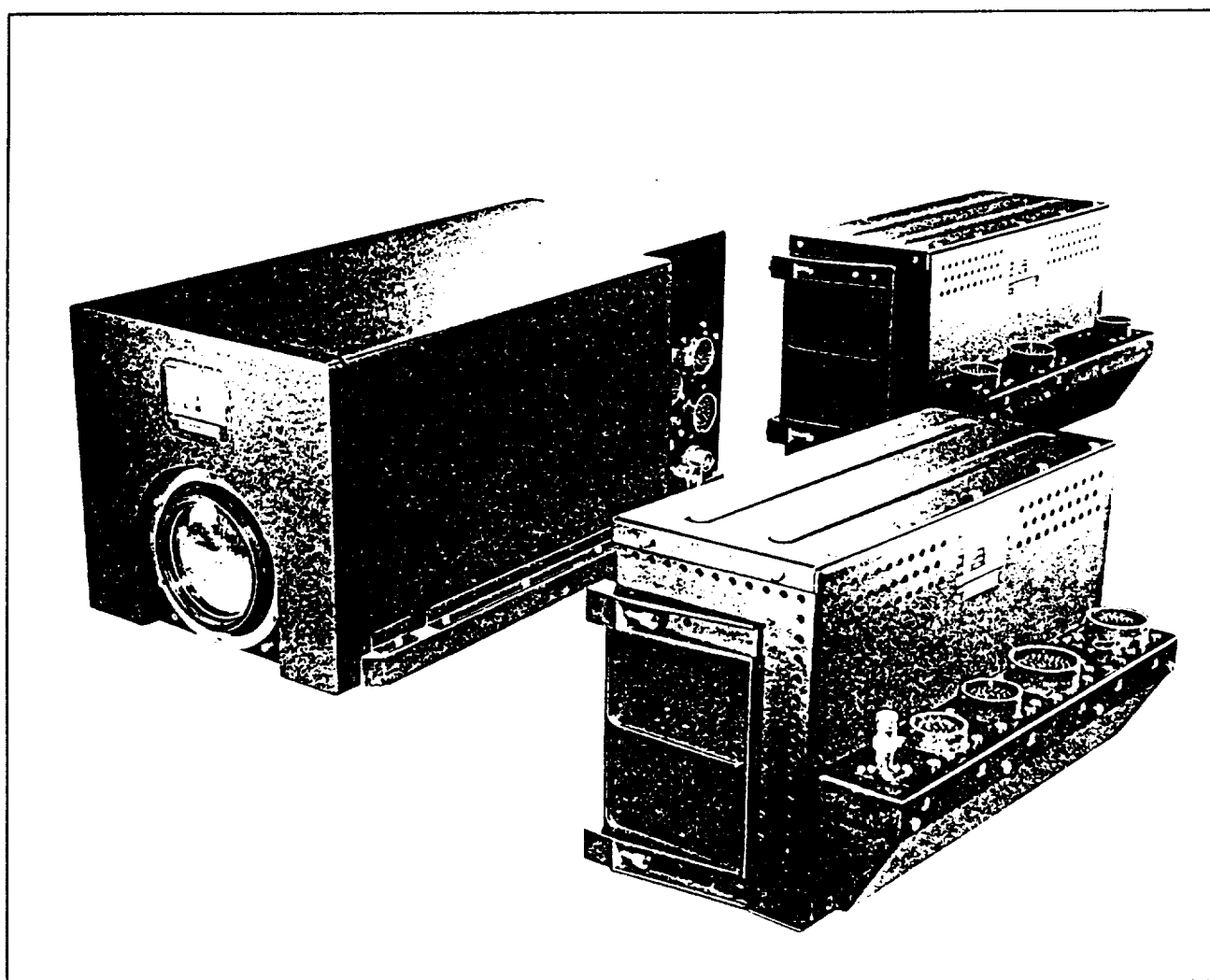


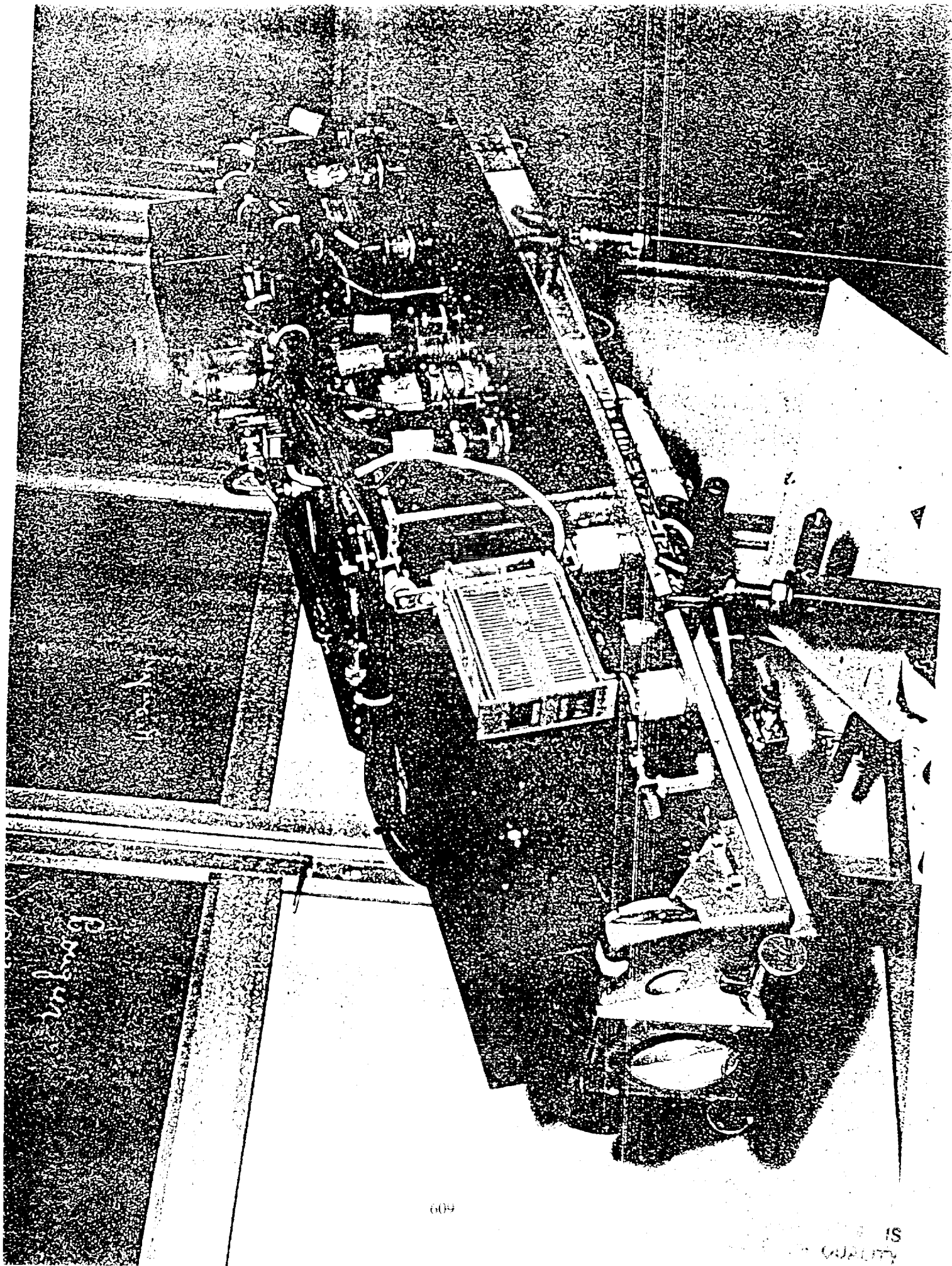
Baie de commande

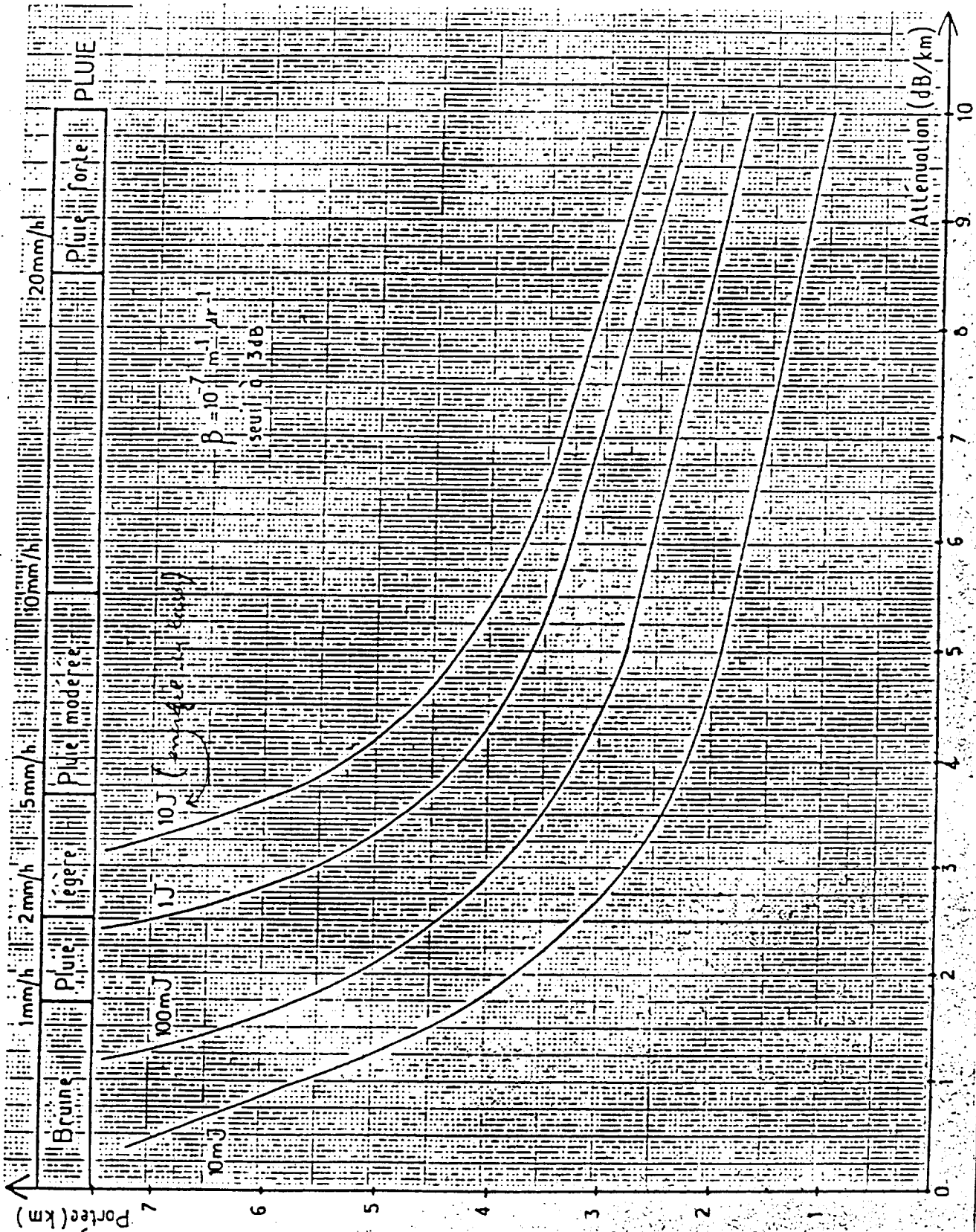


tête optique

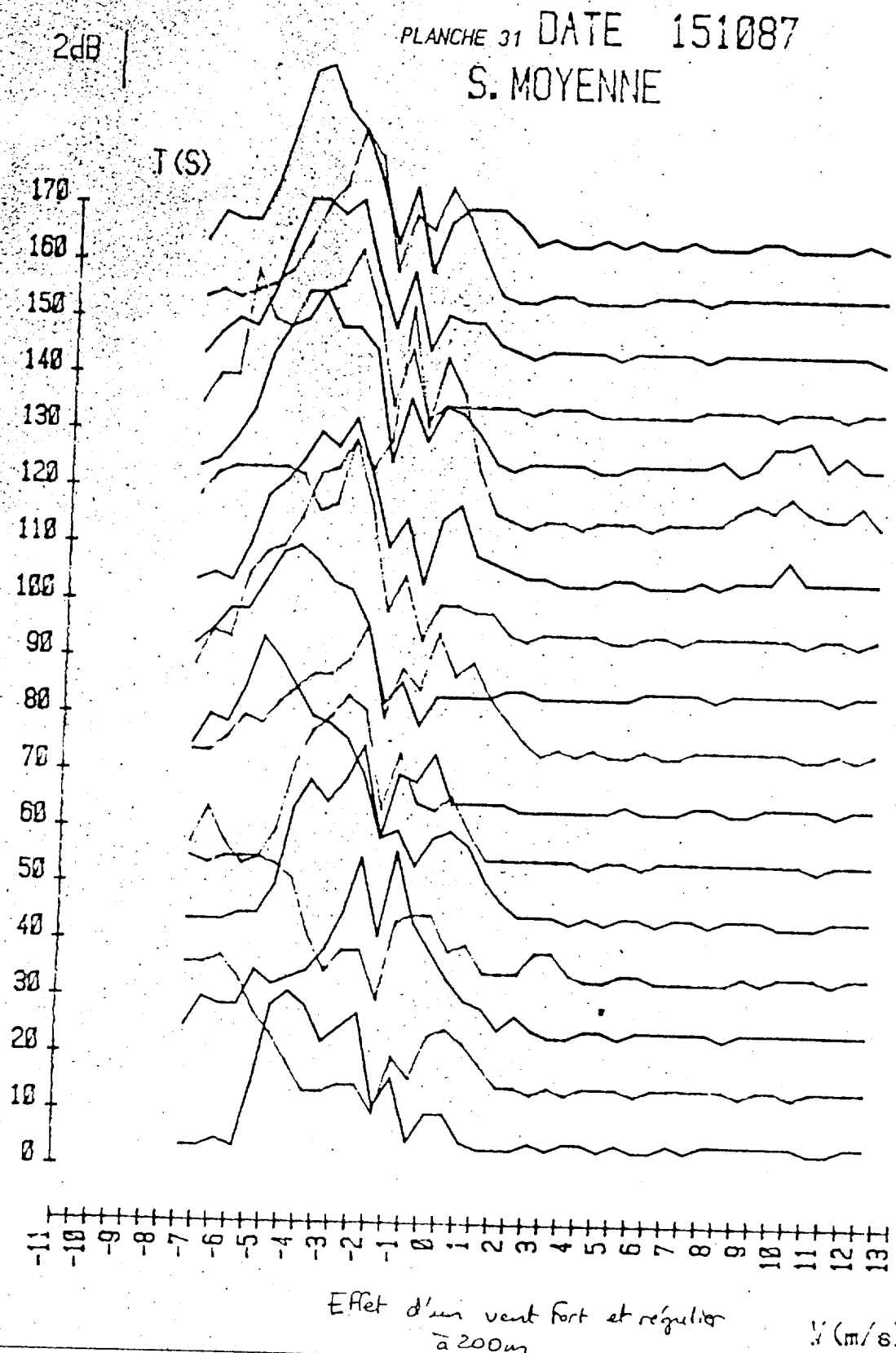
Anémomètre à laser pour essais en vol

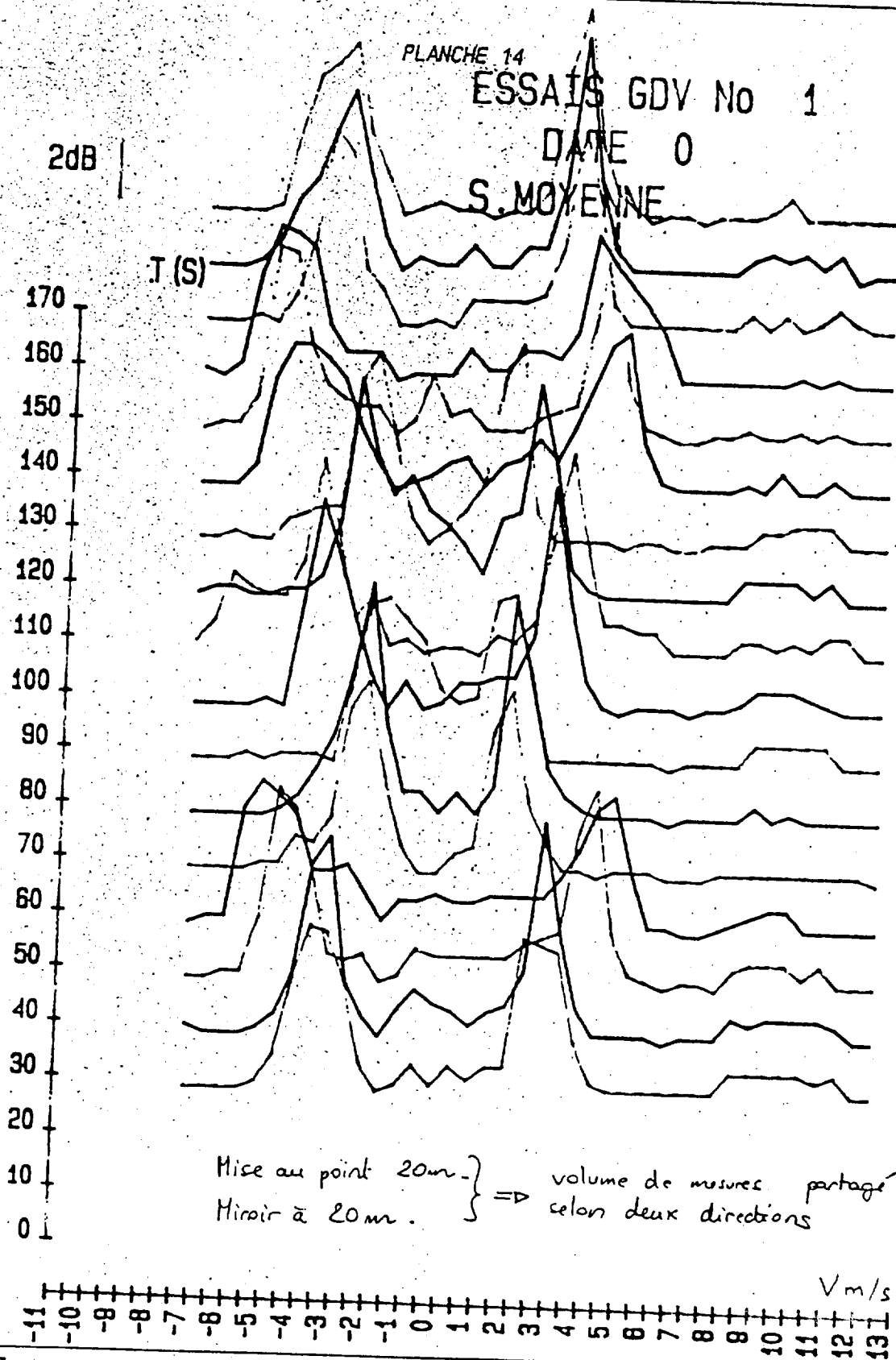






Dégradation des performances par l'atténuation





ESSAI SUR VALENCE : variation continue de 10m à 200m

Reference : AE.TC.87.1966

Rev :

Page : 12

(GDV) RAPPORT S/N

S/N (dB)

20

15

10

5

0

PLANCHE 12

passage d'hélicoptère

T (s)

240

210

180

150

120

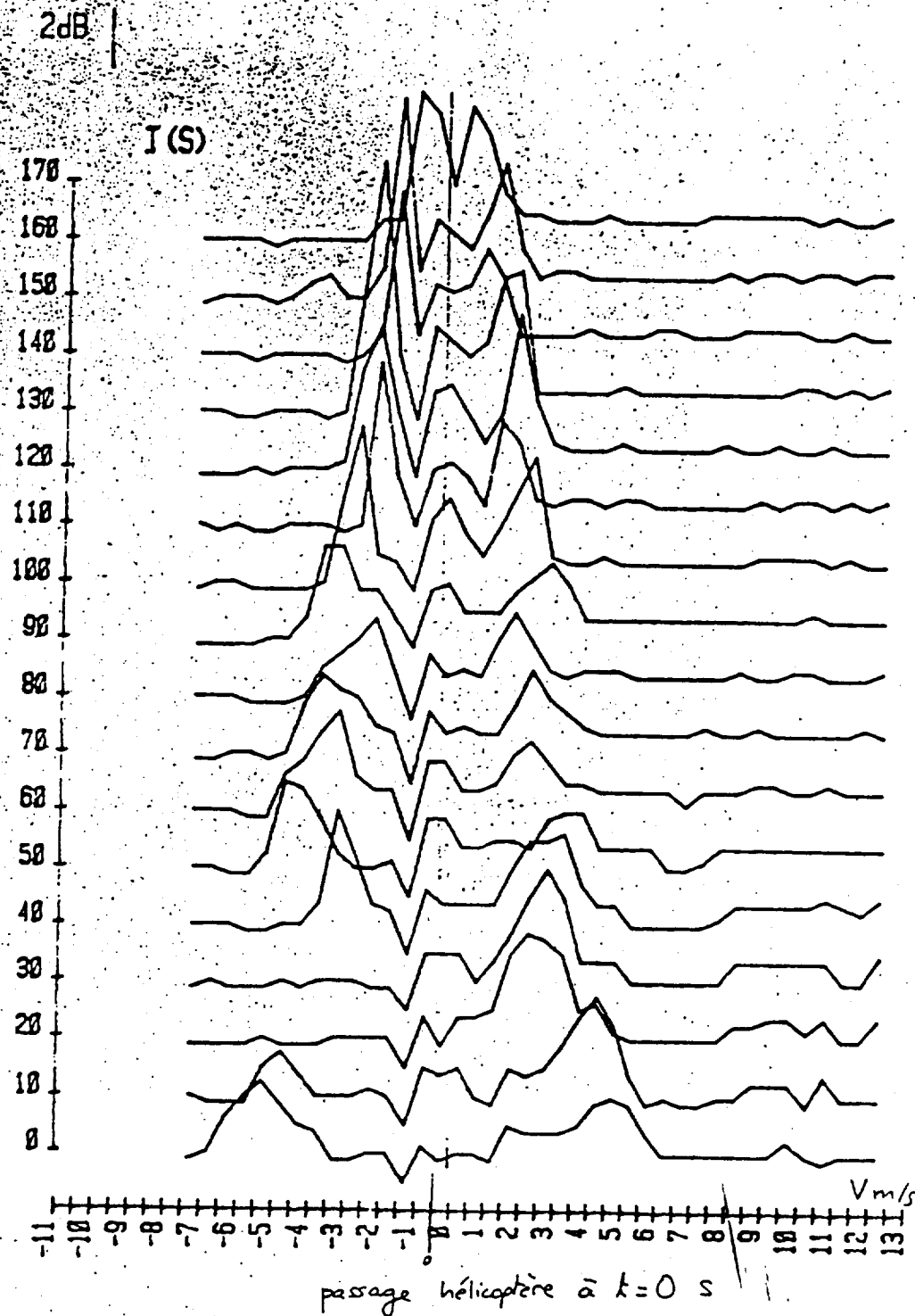
90

60

30

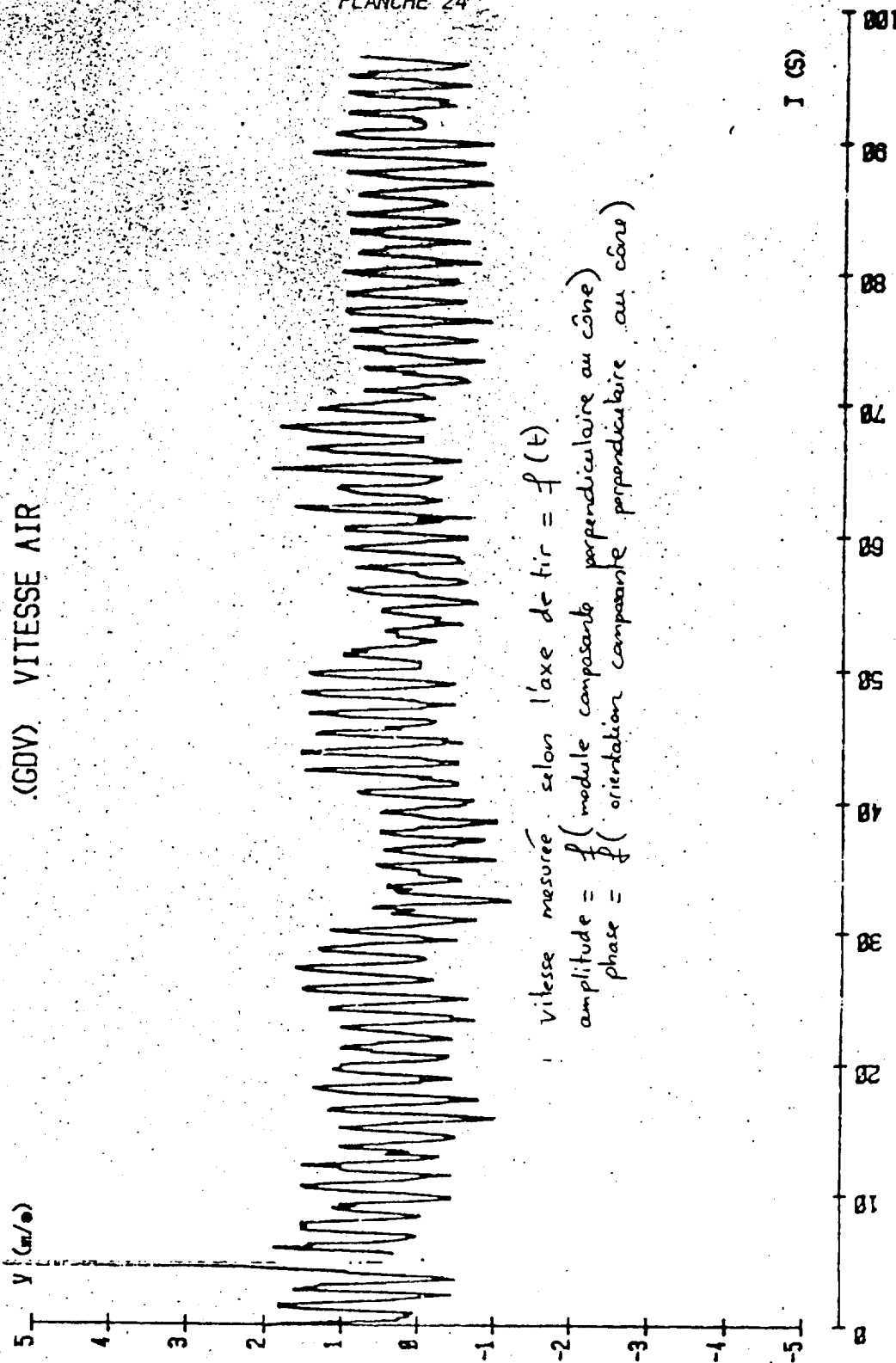
0

PLANCHE 18



(GDV) VITESSE AIR

PLANCHE 24



Vitesse mesurée selon l'axe de tir = $f(t)$
 amplitude = f (module composante perpendiculaire au cône)
 phase = ϕ (orientation composante perpendiculaire au cône)

(GDV) VITESSE AIR

PLANCHE 25

"accidents" de la sinusoïde dus aux inhomogénéités du champ de vent.

v (m/s)

5
4
3
2
1
0
-1
-2
-3
-4
-5

0 1 2 3 4 5 6 7 8 9 10

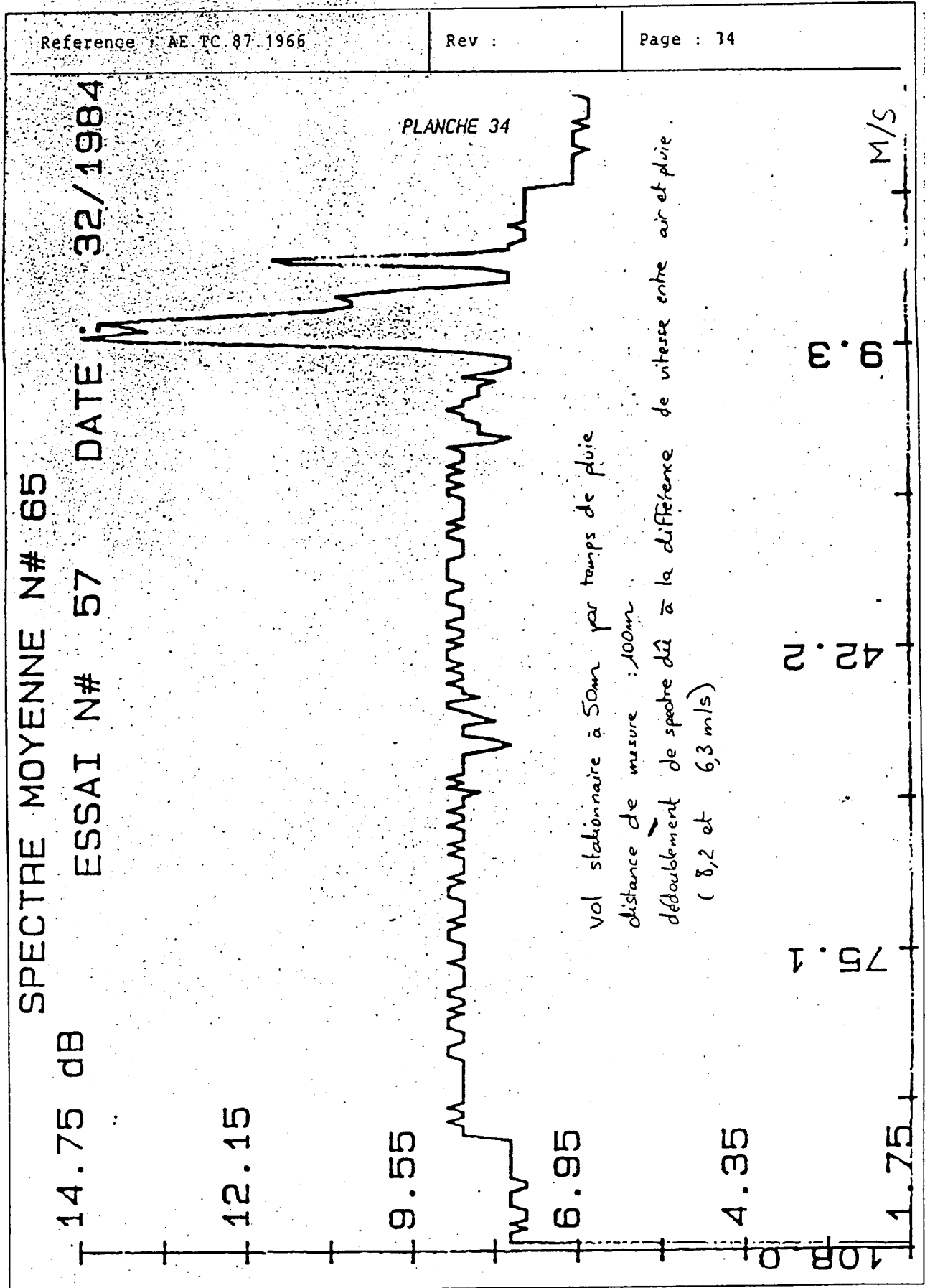
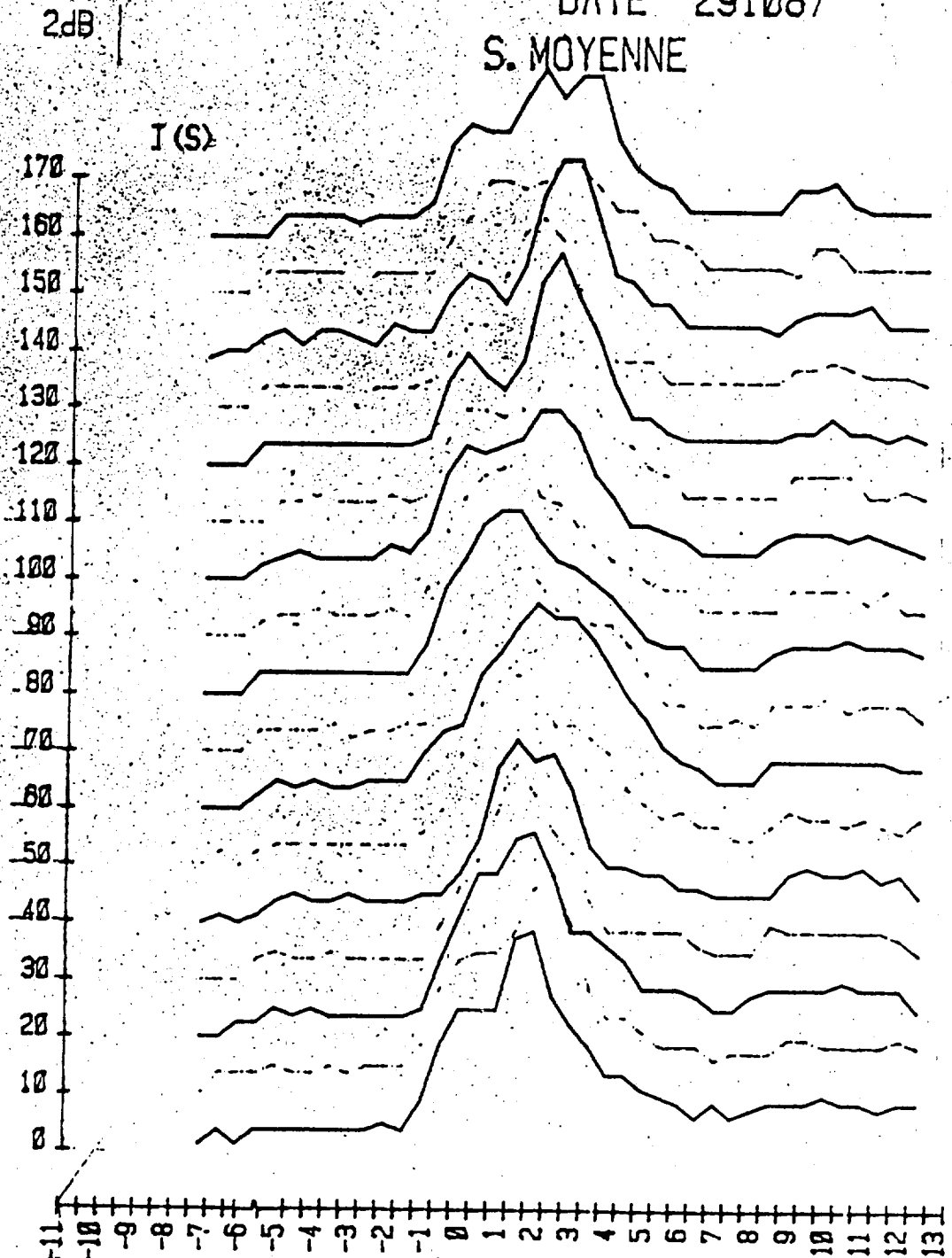


PLANCHE 35

DATE 291087

S. MOYENNE

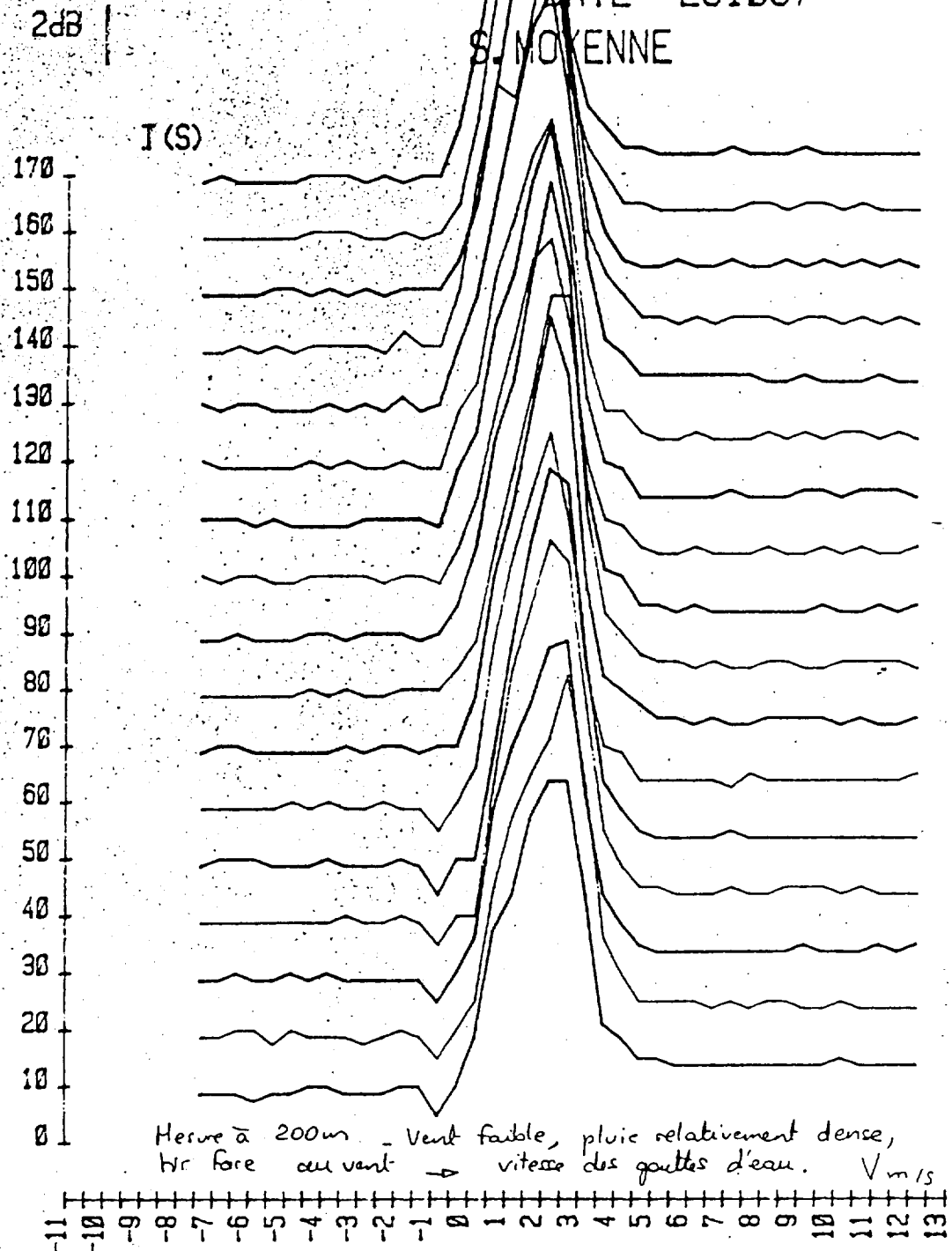


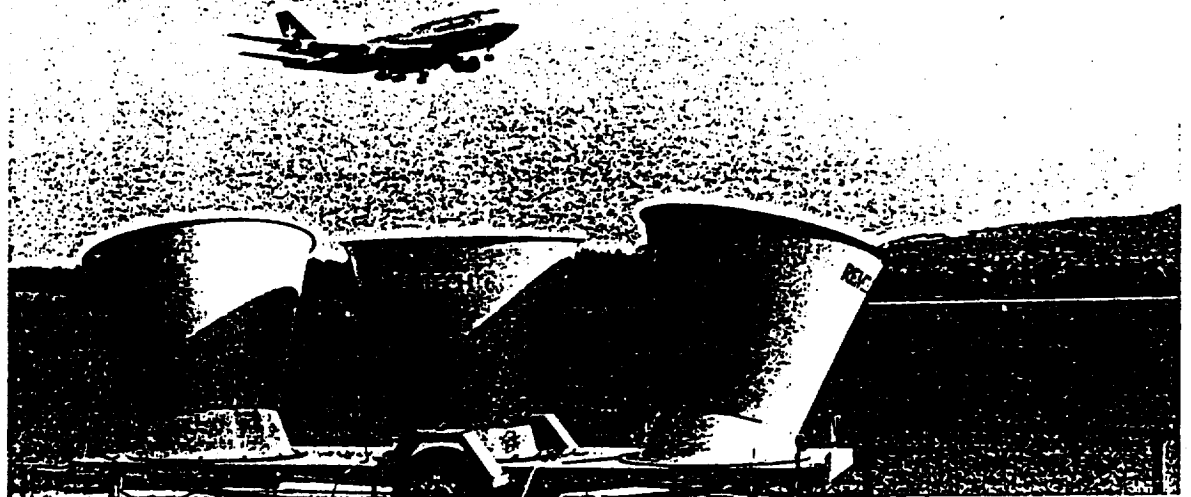
Mesure à 100m par vent léger fluctuant avec
 pluie moyenne -
 Spectres élargis par vitesses variables pluie et
 turbulences

V (m/s)

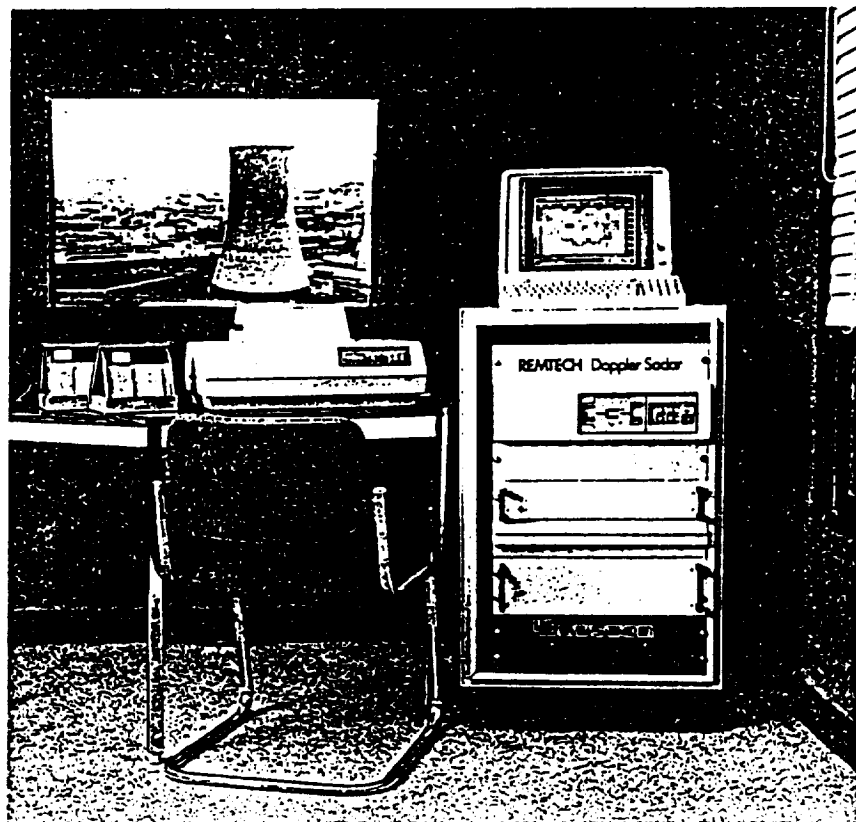
PLANCHE 36

ESSAIS
DATE 291087
S. MOYENNE





SODAR antennae at Zürich Airport



SODAR electronic cabinet

--0 66 0--

1	6	10	36	11	15	1	0	0	255		
RANGE	ECHO	S ECHO	SPEED	TETA	S TETA	W	S W	ETAM	STA	S U	S V
CTS		0.000									
INV	0	0	0	0	0	0	0	0	0	0	0
440	-9999	-9999									
420	-9999	-9999									
400	-9999	-9999									
380	-9999	-9999									
360	-9999	-9999									
340	-9999	-9999									
320	-9999	-9999									
300	-9999	-9999									
280	-9999	-9999									
260	-9999	-9999									
240	-9999	-9999									
220	-9999	-9999									
200	-9999	-9999									
180	-9999	-9999									
160	140	59	-9999	-9999	-9999	-112	163	0	0	0	0
140	145	42	-9999	-9999	-9999	-144	145	0	0	0	0
120	190	55	-9999	-9999	-9999	-142	134	0	0	0	0
100	245	56	-9999	-9999	-9999	-127	135	0	0	0	0
80	249	40	-9999	-9999	-9999	-157	145	0	0	0	0
60	259	28	-9999	-9999	-9999	-164	163	0	0	0	0
10	0	0	0	90	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0

DM	6	10	36	11	29	59	0	0	481		
RANGE	ECHO	S ECHO	SPEED	TETA	S TETA	W	S W	ETAM	STA	S U	S V
CTS		0.000									
INV	0	0	0	0	0	0	0	0	0	0	0
440	-9999	-9999									
420	-9999	-9999									
400	-9999	-9999									
380	-9999	-9999									
360	-9999	-9999									
340	-9999	-9999									
320	-9999	-9999									
300	-9999	-9999									
280	-9999	-9999									
260	-9999	-9999									
240	-9999	-9999									
220	84	51	-9999	-9999	-9999	-226	120	0	0	0	0
200	103	39	-9999	-9999	-9999	-181	147	0	0	0	0
180	100	40	-9999	-9999	-9999	-242	145	0	0	0	0
160	102	51	-9999	-9999	-9999	-169	138	0	0	0	0
140	113	52	-9999	-9999	-9999	-157	133	0	0	0	0
120	134	49	-9999	-9999	-9999	-177	131	0	0	0	0
100	166	60	-9999	-9999	-9999	-177	123	0	0	0	0
80	185	51	-9999	-9999	-9999	-168	124	0	0	0	0
60	231	43	-9999	-9999	-9999	-144	109	0	0	0	0
10	0	0	0	90	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0

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DM	7	3	37	12	50	0	0	0	572		
RANGE	ECHO S	ECHO	SPEED	TETA S	TETA	W	S W	ETAM	STA	S U	S V
CTC		0.000									
INV	0	0	0	0	0	0	0	0	0	0	0
400	-9999	-9999									
380	-9999	-9999									
360	-9999	-9999									
340	-9999	-9999									
320	-9999	-9999									
300	133	53	-9999	-9999	-9999	363	49	0	0	0	0
280	-9999	-9999									
260	178	40	-9999	-9999	-9999	375	65	0	0	0	0
240	183	53	-9999	-9999	-9999	325	103	0	0	0	0
220	203	51	-9999	-9999	-9999	321	121	0	0	0	0
200	232	50	-9999	-9999	-9999	334	115	0	0	0	0
180	233	64	-9999	-9999	-9999	333	90	0	0	0	0
160	284	53	-9999	-9999	-9999	316	75	0	0	0	0
140	349	52	-9999	-9999	-9999	317	67	0	0	0	0
120	411	46	-9999	-9999	-9999	323	74	0	0	0	0
100	401	38	-9999	-9999	-9999	317	93	0	0	0	0
80	362	32	-9999	-9999	-9999	265	105	0	0	0	0
60	339	20	-9999	-9999	-9999	235	140	0	0	0	0
10	0	0	0	90	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0

DM	7	3	37	12	59	59	0	0	639		
RANGE	ECHO S	ECHO	SPEED	TETA S	TETA	W	S W	ETAM	STA	S U	S V
CTC		0.000									
INV	0	0	0	0	0	0	0	0	0	0	0
400	-9999	-9999									
380	-9999	-9999									
360	-9999	-9999									
340	-9999	-9999									
320	-9999	-9999									
300	143	30	-9999	-9999	-9999	242	93	0	0	0	0
280	123	47	-9999	-9999	-9999	270	75	0	0	0	0
260	-9999	-9999									
240	166	82	-9999	-9999	-9999	179	75	0	0	0	0
220	205	68	-9999	-9999	-9999	204	82	0	0	0	0
200	182	62	-9999	-9999	-9999	175	91	0	0	0	0
180	252	63	-9999	-9999	-9999	178	95	0	0	0	0
160	302	76	-9999	-9999	-9999	168	92	0	0	0	0
140	316	62	-9999	-9999	-9999	174	88	0	0	0	0
120	393	33	-9999	-9999	-9999	176	89	0	0	0	0
100	423	33	-9999	-9999	-9999	148	100	0	0	0	0
80	416	25	-9999	-9999	-9999	142	106	0	0	0	0
60	364	16	-9999	-9999	-9999	133	94	0	0	0	0
10	0	0	0	90	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0

Figure 1

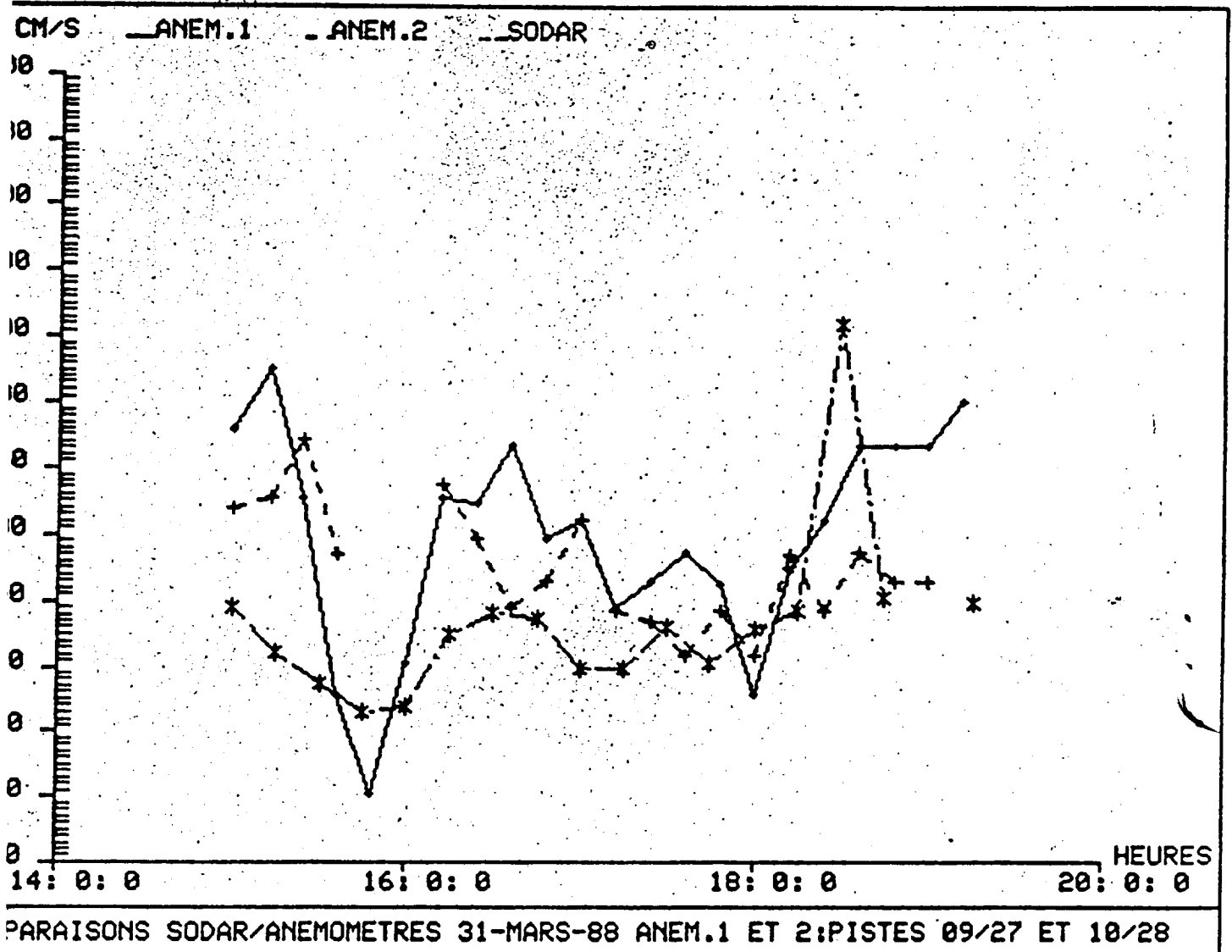


Figure 2

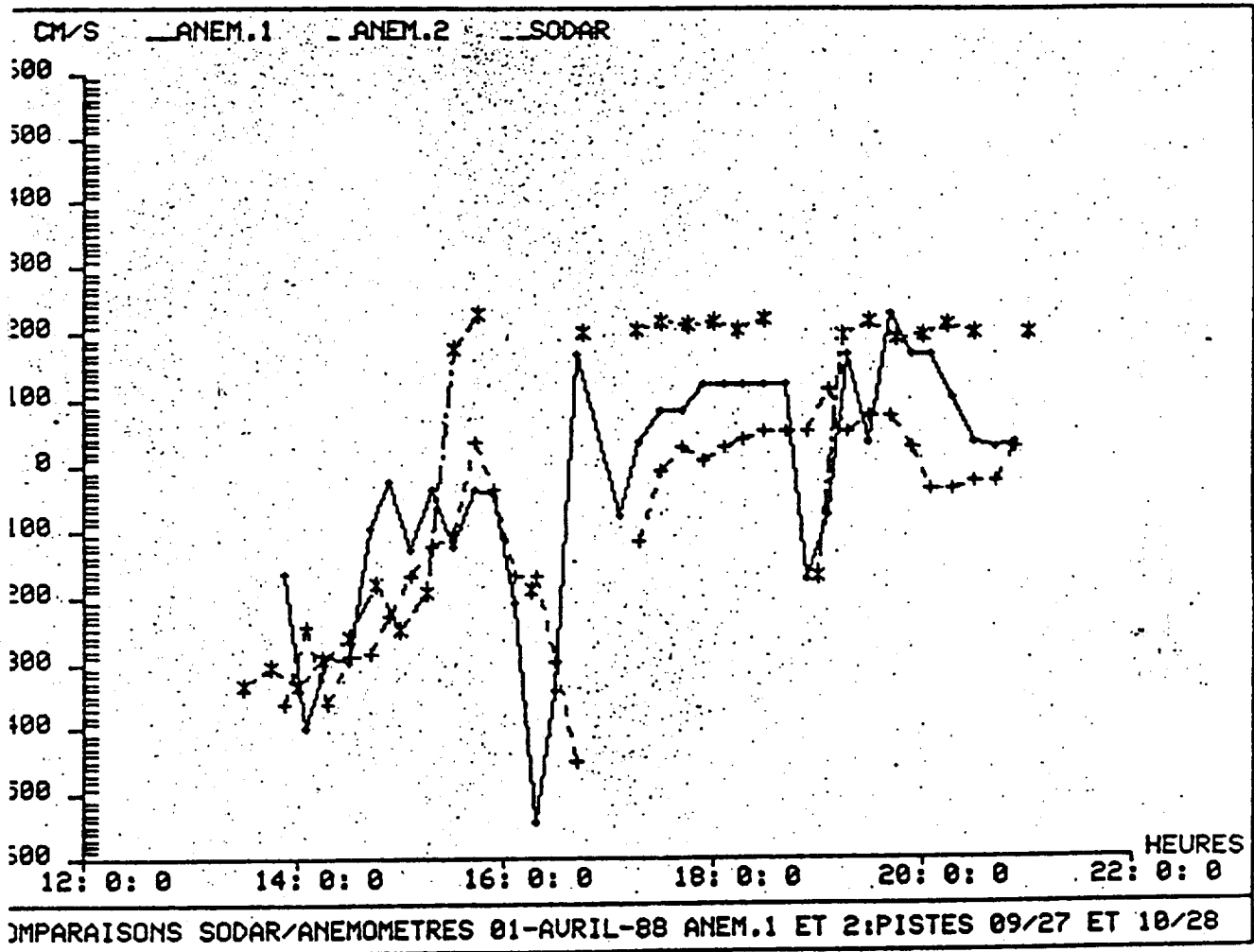
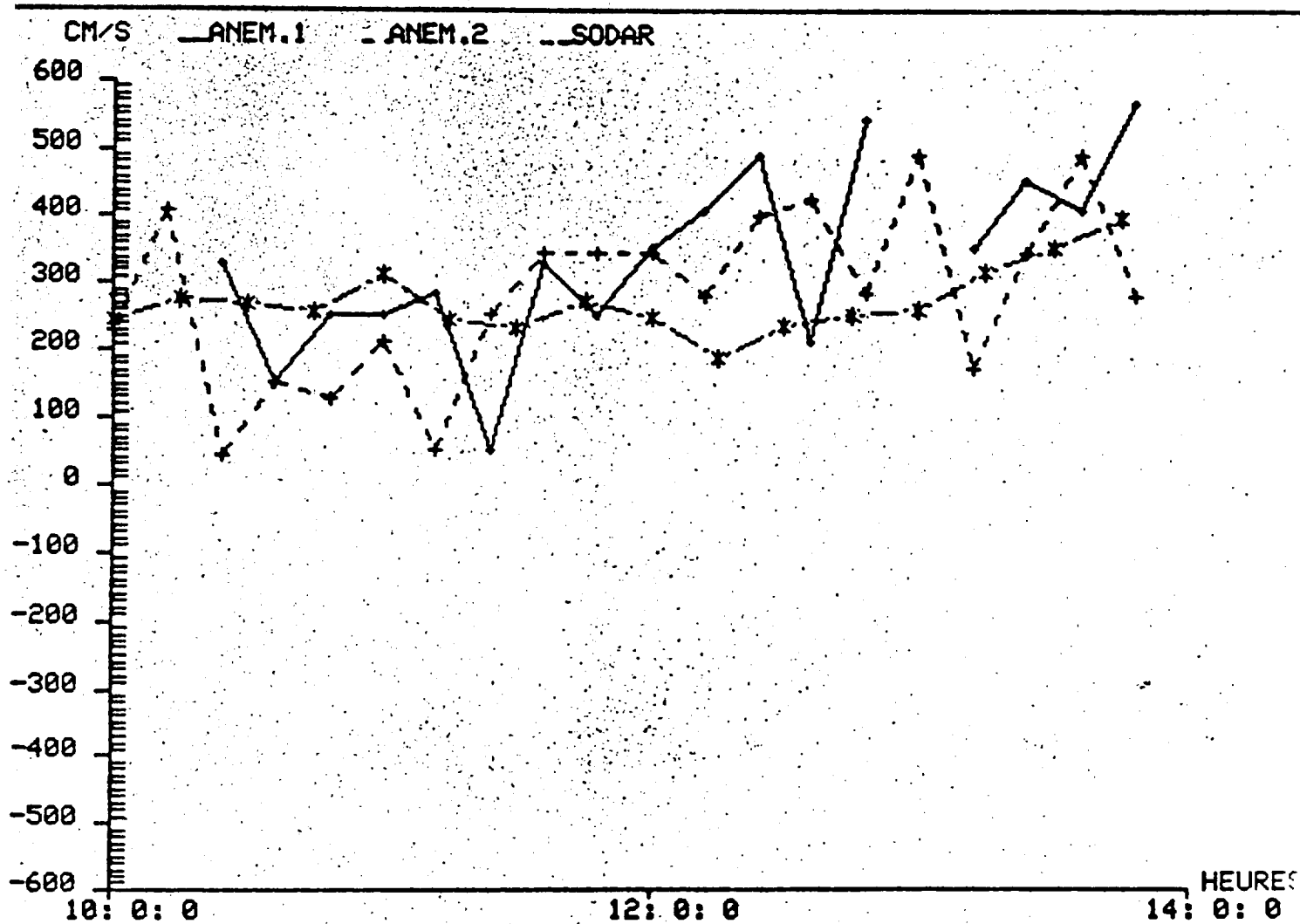
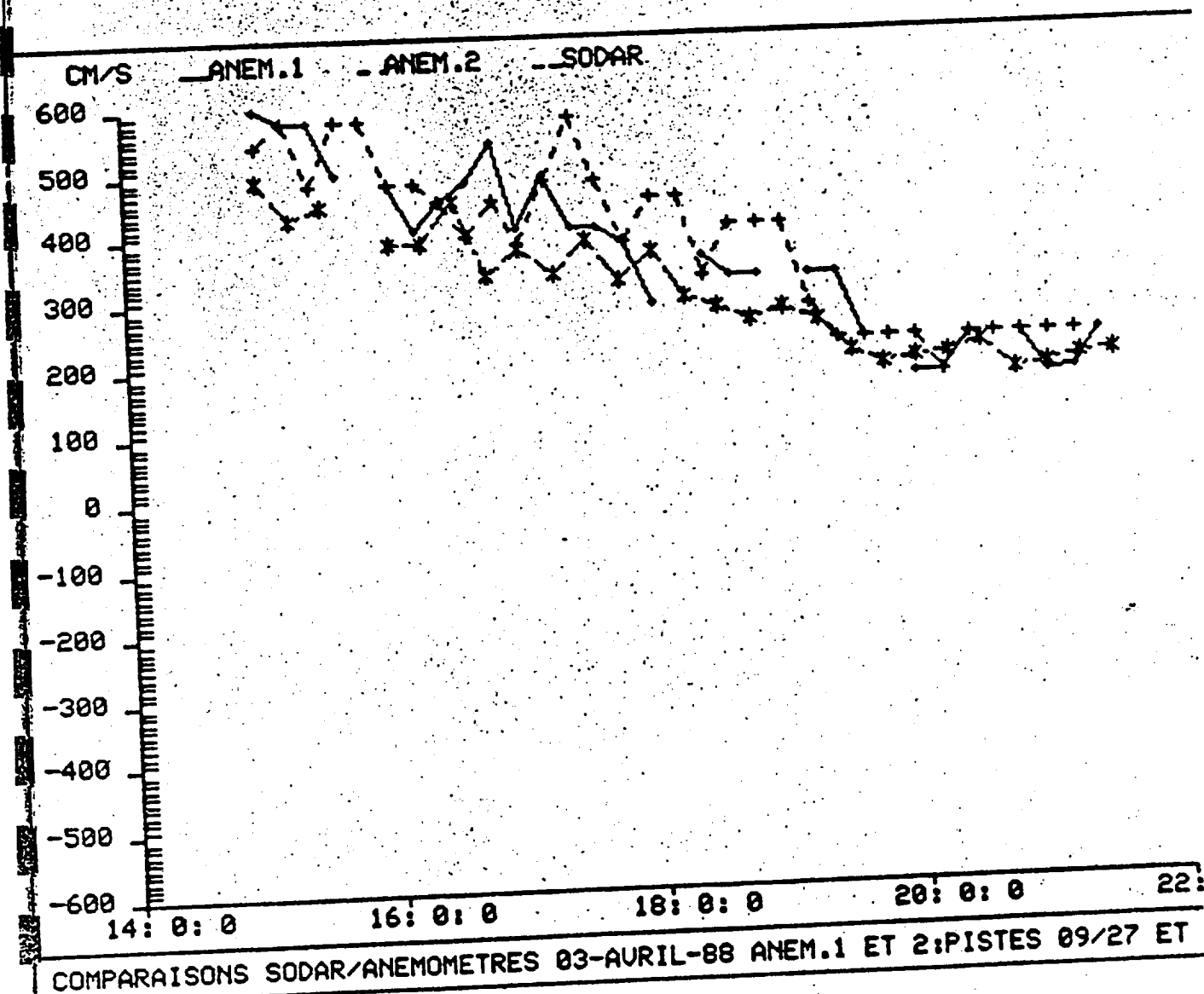


Figure 3



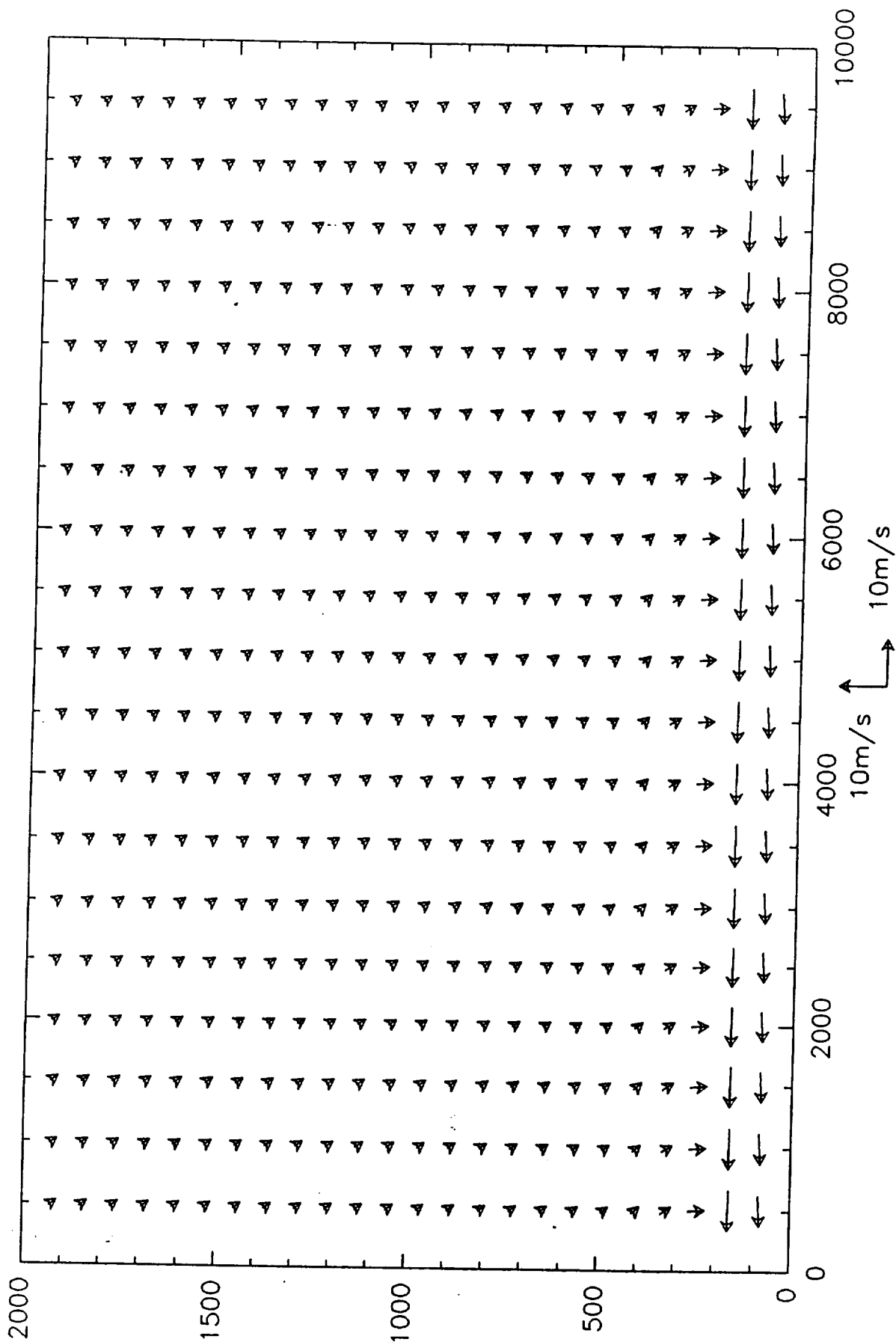
COMPARAISONS SODAR/ANEMOMETRES 02-AVRIL-88 ANEM.1 ET 2:PISTES 09/27 ET 10/28

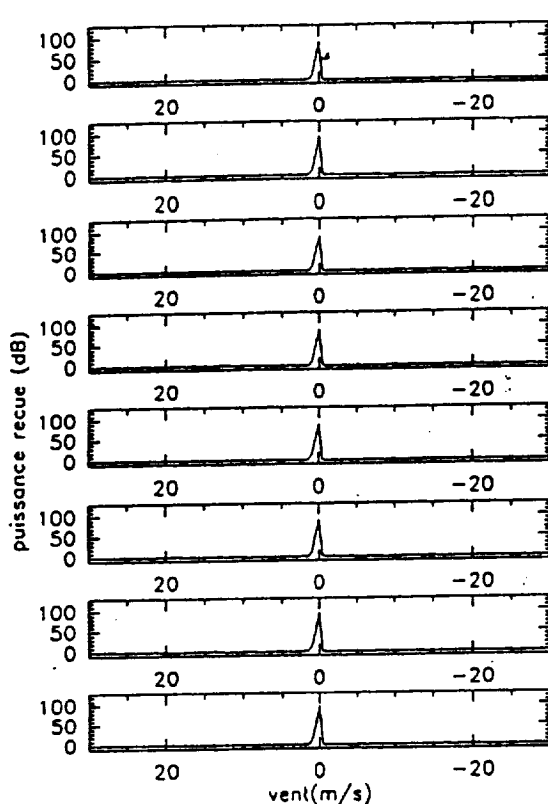
Figure 4



WIND SPEED 15
IN KNOTS QUALITY

modele 6 decollage





porte 15
zmax(m)=1923.0
zmin(m)=1340.0

porte 14
zmax(m)=1804.0
zmin(m)=1251.0

porte 13
zmax(m)=1684.0
zmin(m)=1162.0

porte 12
zmax(m)=1564.0
zmin(m)=1074.0

porte 11
zmax(m)=1445.0
zmin(m)= 985.0

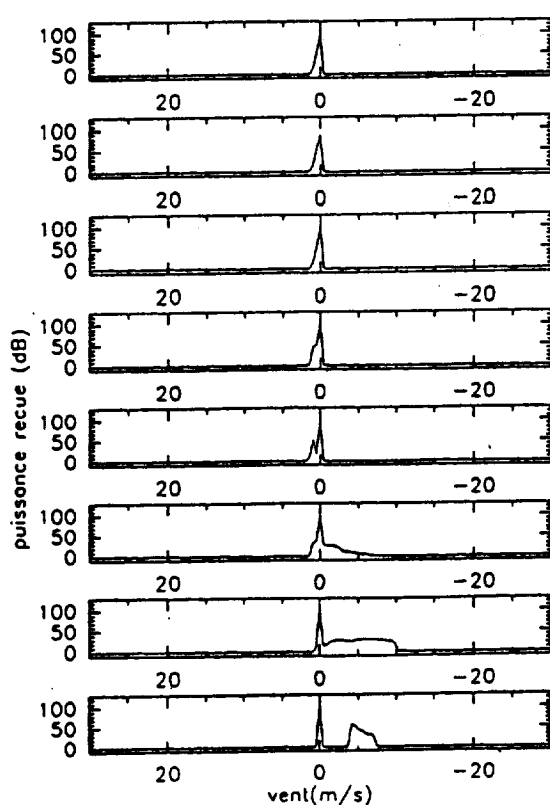
porte 10
zmax(m)=1325.0
zmin(m)= 896.0

porte 9
zmax(m)=1206.0
zmin(m)= 808.0

porte 8
zmax(m)=1086.0
zmin(m)= 719.0

altitude du radar(m) = 10.0
puissance crete(W) = 4500.
larg-impulsion(micro-s) = 4.00
longueur d'onde(cm) = 30.00
angle de visée(deg) = 80.00
ouverture-antenne(deg) = 1.50
gain de l'antenne(dB) = 41.7
niveau-lobes-second.(dB) = 20.0

$Z_e = 0 \text{ dB}_z$



porte 7
zmax(m)= 966.0
zmin(m)= 630.0

porte 6
zmax(m)= 847.0
zmin(m)= 542.0

porte 5
zmax(m)= 727.0
zmin(m)= 453.0

porte 4
zmax(m)= 608.0
zmin(m)= 364.0

porte 3
zmax(m)= 488.0
zmin(m)= 276.0

porte 2
zmax(m)= 368.0
zmin(m)= 187.0

porte 1
zmax(m)= 249.0
zmin(m)= 98.0

porte 0
zmax(m)= 129.0
zmin(m)= 10.0

modele 6

decollage

donc une éventuelle variation des valeurs extrêmes du vent observé.

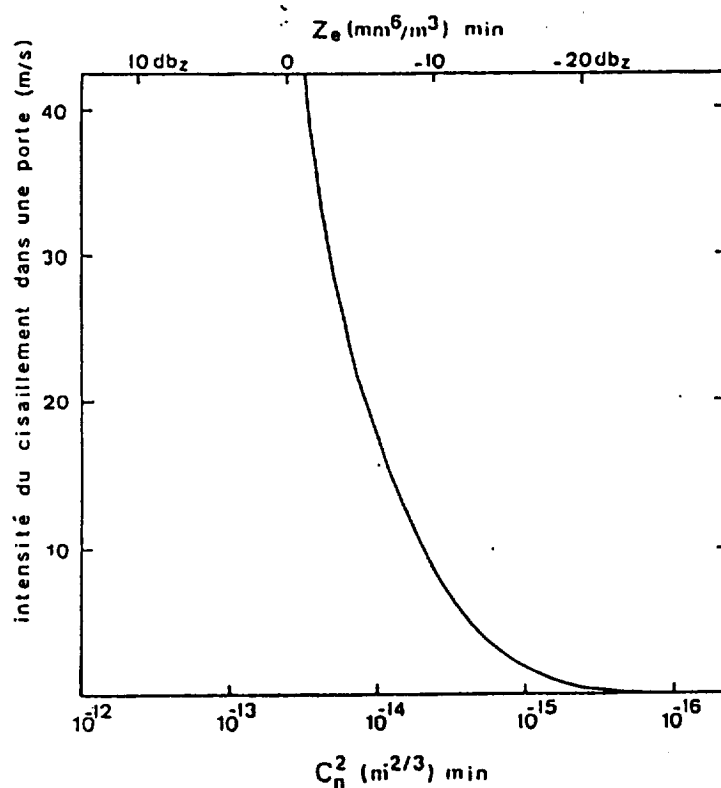


Figure (1,4) Réflectivité minimum (exprimée en C_n^2) requise à une distance $r = 10\text{km}$ pour assurer une bonne détectabilité d'un cisaillement de vent d'amplitude donnée en ordonnée. On retrouve, pour un cisaillement de vent nul, la valeur théorique calculée au § (I.1.3.a).

cisaillement de vent en présence d'échos de sol sont fournis en Annexe V. Les principaux résultats de cette simulation en ce qui concerne les échos de sol sont résumés dans les figures (2,7) et (2,8) ci après.

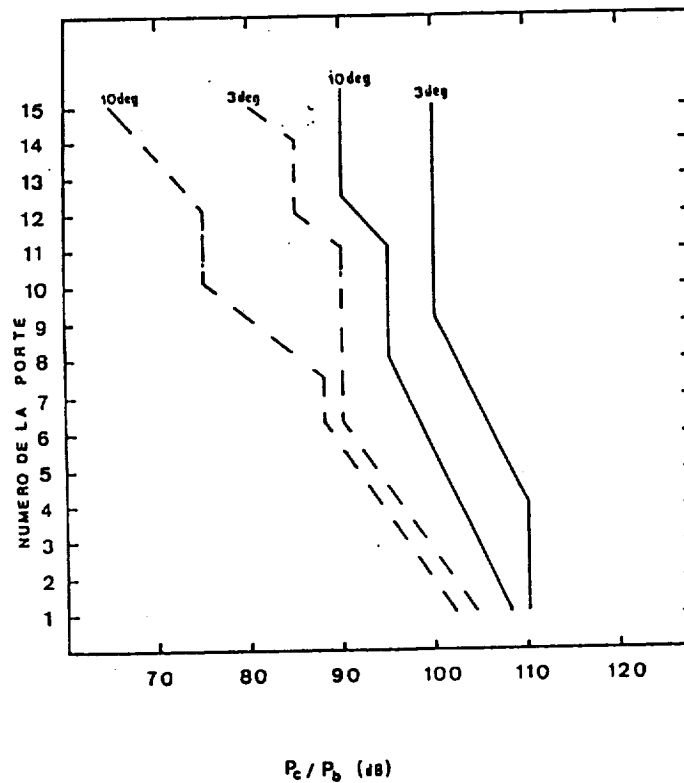


Figure (2,7): variation du rapport puissance clutter/ puissance bruit par filtre équivalent FFT, en fonction de la distance (portes 1 à 15); pour deux valeurs de l'angle de visée ($\alpha = 3 \text{ deg}$ et $\alpha = 10 \text{ deg}$); et pour deux valeurs différentes du niveau des lobes secondaires de l'antenne:

20 dB en traits pleins

30 dB en tiretés

L'ouverture de l'antenne est ici de $\Theta = 4 \text{ deg}$

Dans cette simulation, on a fait varier l'ouverture de l'antenne (Θ); l'angle de visée (α); et le niveau des lobes secondaires. Le tableau ci-dessous donne l'ensemble des variations utilisées :

Θ	Niveau lobes secondaires	angles de visée
3°	-20 dB ; -30 dB	3° et 10°
4°	-20 dB ; -30 dB	3° et 10°

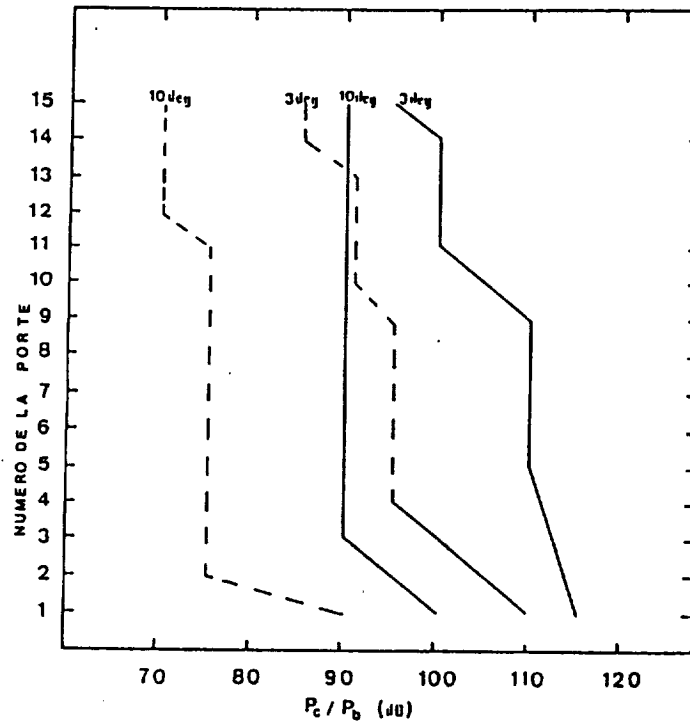


Figure (2,8) : même chose que sur la fig.(2,7) mais avec une antenne d'ouverture $\Theta = 3$ deg.

L'analyse de cette simulation appelle plusieurs remarques.

1°) Le rapport Puissance de l'écho/Puissance du Bruit (P_c/P_b) varie en fonction de la distance pour chaque ouverture d'antenne et angle de visée. Les figures (2.7) et (2.8) résument les variations obtenues dans chaque porte radar (15 portes de 600m) en fonction de l'angle de visée pour des niveaux de lobes secondaires de -20 et -30 dB et pour deux valeurs d'ouverture d'antenne : $\Theta = 4^\circ$ (fig. 2.7) et $\Theta = 3^\circ$ (fig. 2.8).

Pour $\Theta = 4^\circ$ le rapport P_c/P_b est peu sensible (dans les premières portes) aux variations de l'angle de visée et au niveau des lobes secondaires. Il reste à un niveau de

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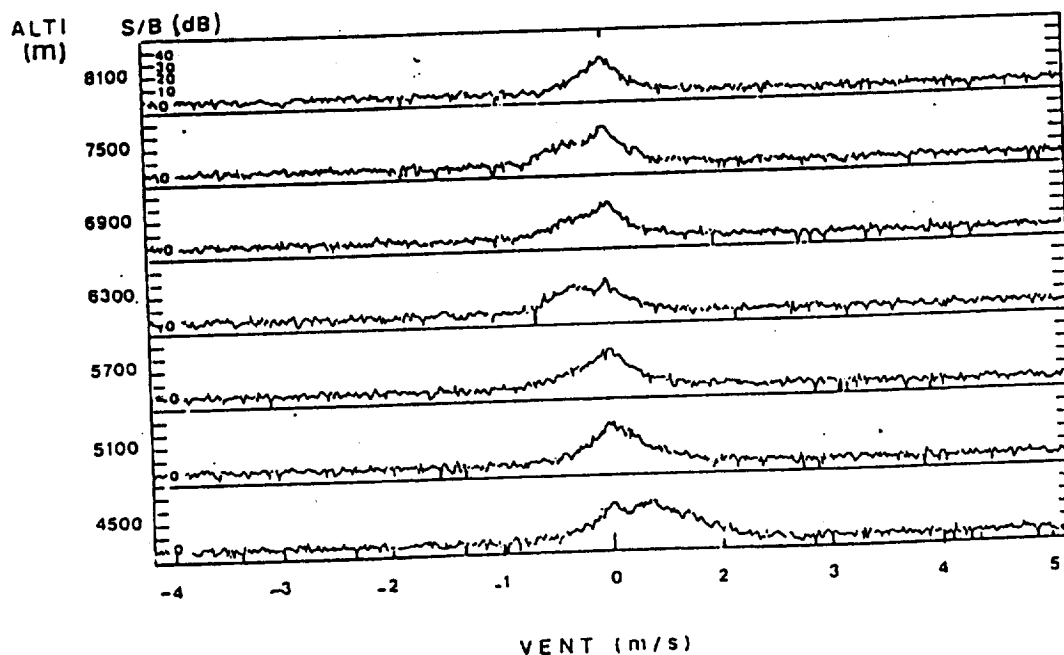


Figure (2,9) : Spectres bruts obtenus à Saint Santin par le radar PROUST visant à la verticale (rapport Signal/Bruit en fonction de la fréquence exprimée en terme de vent vertical) pour les portes 4 à 10 (4500m à 8100m d'altitude). La situation météorologique est anticyclonique et le ciel sans nuages. Les échos de sol occupent le centre du spectre (autour du Doppler nul) dans un domaine spectral correspondant à ± 0.6 m/s. On voit également apparaître un signal "air clair" qui est dans certaines portes entièrement masqué par l'écho de sol

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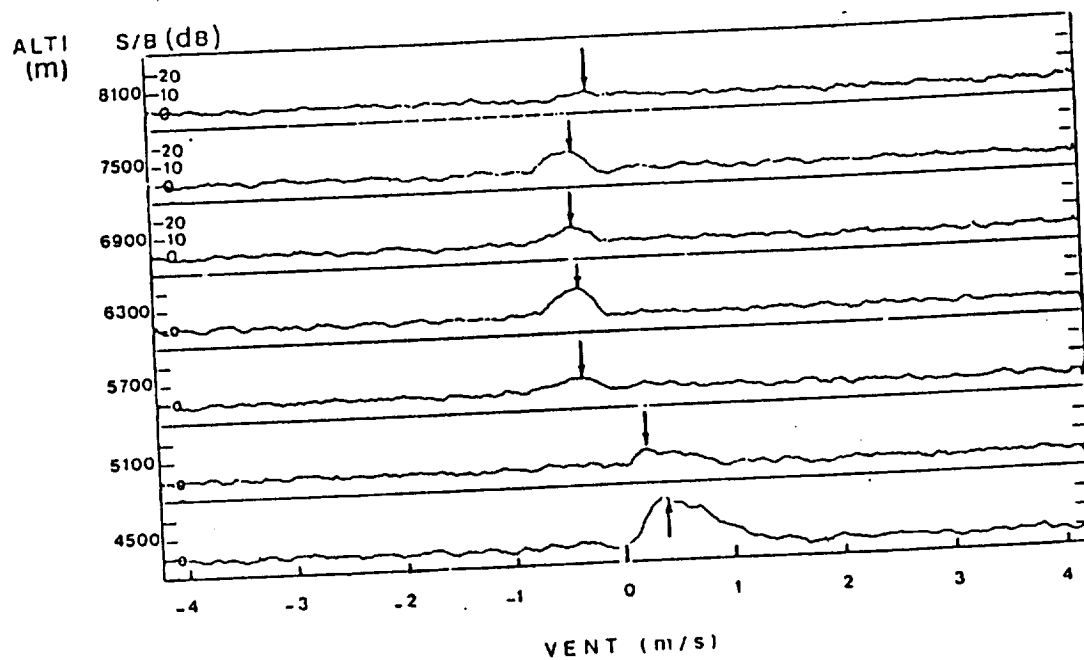
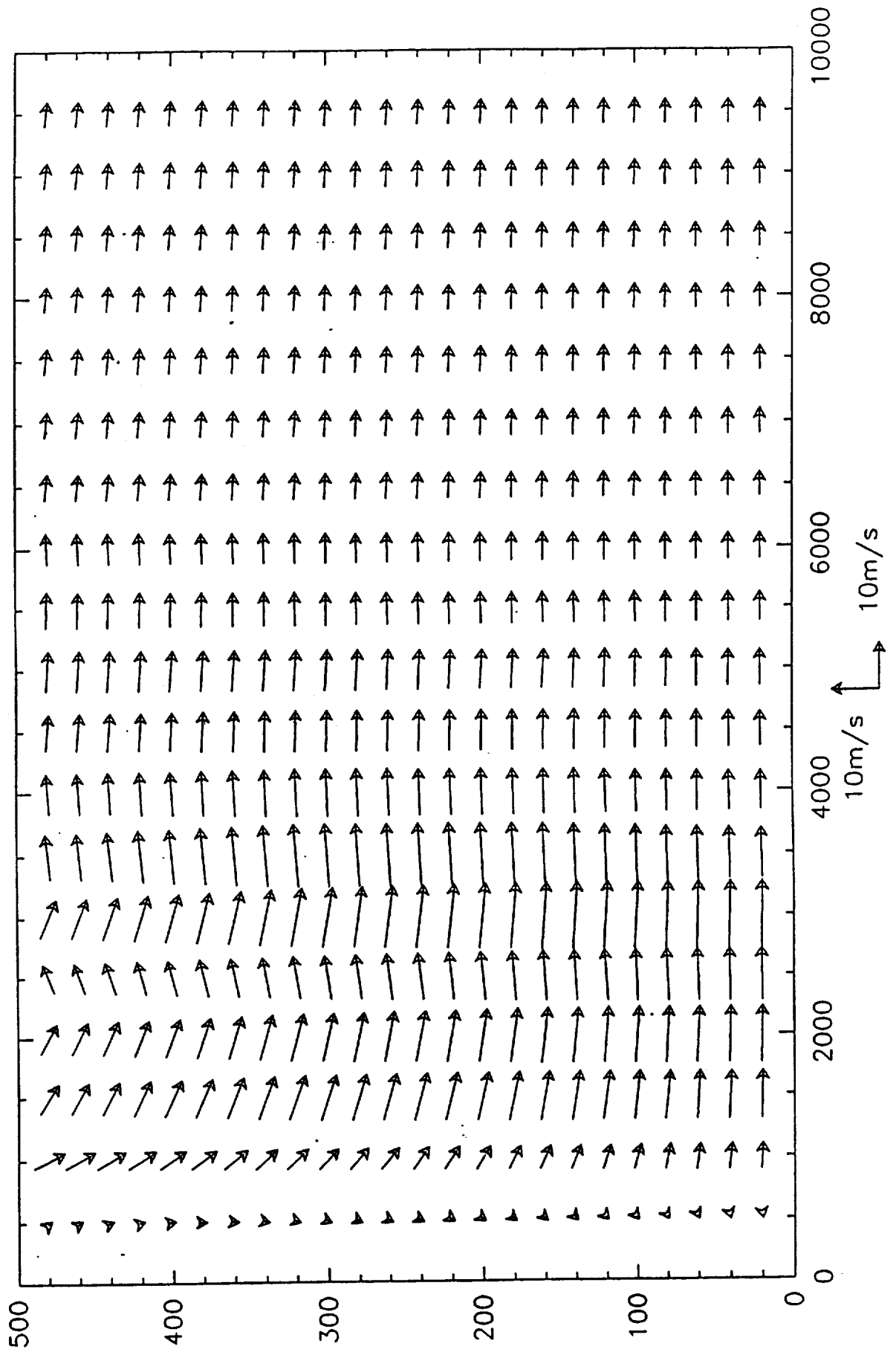


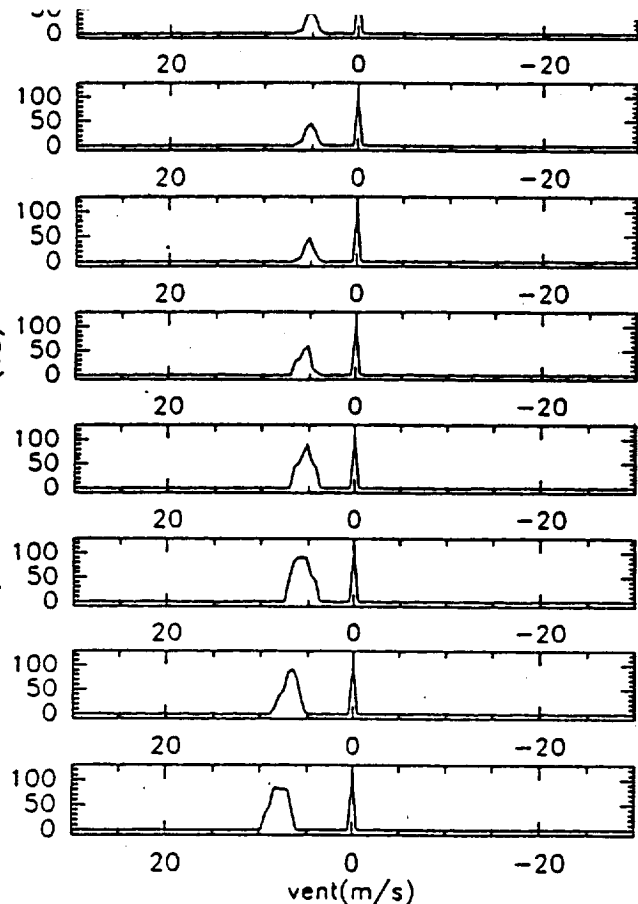
Figure (2,10) : Spectres atmosphériques "air clair" obtenus après élimination des échos de sol par la méthode d'ajustement décrite dans le § 1.2.1.6.2.2°.

modele 14 atterrissage



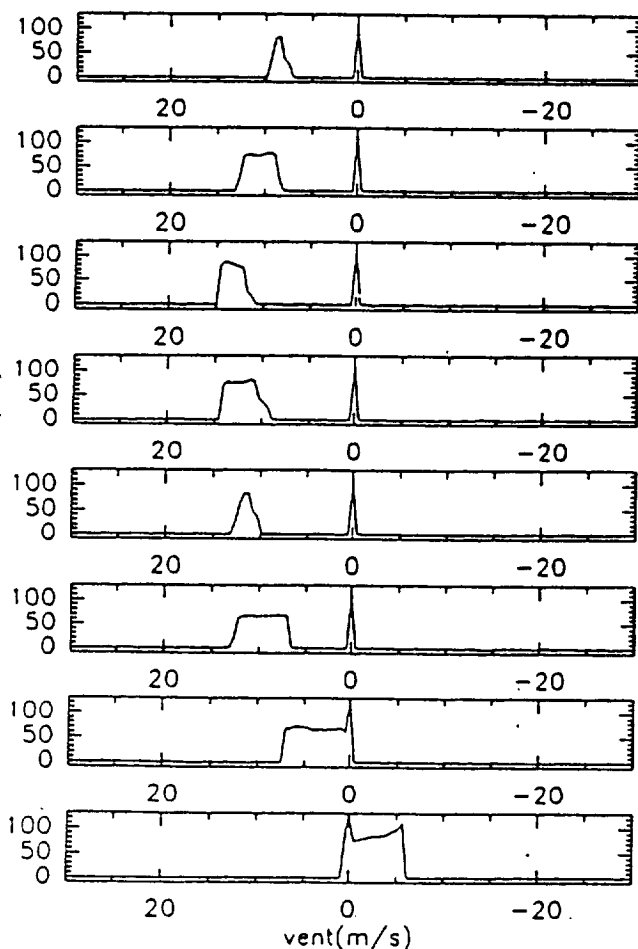
puissance reçue (dB)

puissance reçue (dB)



zmin(m)= 245.0
 porte 14
 zmax(m)= 715.0
 zmin(m)= 229.0
 porte 13
 zmax(m)= 668.0
 zmin(m)= 214.0
 porte 12
 zmax(m)= 621.0
 zmin(m)= 198.0
 porte 11
 zmax(m)= 574.0
 zmin(m)= 182.0
 porte 10
 zmax(m)= 527.0
 zmin(m)= 166.0
 porte 9
 zmax(m)= 480.0
 zmin(m)= 151.0
 porte 8
 zmax(m)= 433.0
 zmin(m)= 135.0

altitude du radar(m) = 10.0
 puissance crete(W) = 4500.
 larg-impulsion(micro-s) = 4.00
 longueur d'onde(cm) = 30.00
 angle de visee(deg) = 87.00
 ouverture-antenne(deg) = 1.50
 gain de l'antenne(dB) = 41.7
 niveau-lobes-second.(dB) = 20.0



porte 7
 zmax(m)= 386.0
 zmin(m)= 119.0
 porte 6
 zmax(m)= 339.0
 zmin(m)= 104.0
 porte 5
 zmax(m)= 292.0
 zmin(m)= 88.0
 porte 4
 zmax(m)= 245.0
 zmin(m)= 72.0
 porte 3
 zmax(m)= 198.0
 zmin(m)= 57.0
 porte 2
 zmax(m)= 151.0
 zmin(m)= 41.0
 porte 1
 zmax(m)= 104.0
 zmin(m)= 25.0
 porte 0
 zmax(m)= 57.0
 zmin(m)= 10.0

modele 14
 atterrissage

modele 8 atterrissage

